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Calcium and phosphorus studies with growing - finishing swine

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CALCIUM AND PHOSPHORUS STUDIES WITH
GROWING - FINISHING SWINE

By

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INTRODUCTION

Several inorganic elements found in bone tissue are metabolic essentials for diverse biochemical processes in animal organisms. For example, sodium and potassium are intimately involved in the maintenance of osmotic pressure in body fluids, calcium is necessary for normal blood coagulation and for activation of certain enzymes, magnesium and potassium are important in activating many of the enzymes' reactions in carbohydrate metabolism, while phosphorus is intimately associated in the metabolism of fats, carbohydrates and protein. These elements are also essential for the development of osseous tissue.

More recent evidence emphasizes that skeletal tissue expresses, simultaneously, extremely labile and stable qualities. It is known that exchange of calcium and phosphorus ions between bone mineral and body fluids is instantaneous. To a lesser degree it is thought that sodium and magnesium may be mobilized from the bone to satisfy the needs of soft tissues of the body. However, reports concerning the metabolic behavior of osseous tissue are not in harmony, and there is a dearth of information concerning dietary effect upon the composition of this tissue.

Livestock obtain their minerals from feed or forage which they may consume and from specific mineral supplements. Numerous investigations have been conducted during the past century demonstrating that skeletal development in animals is affected by the dietary intake of various minerals. These reports have clearly indicated that the problem of mineral metabolism in livestock is complex. The mode of deposition of mineral elements in osseous tissue is not well understood and clarification is needed regarding the nature of this tissue. However, it is known that vitamin D is involved in calcium and phosphorus utilization, and that the ratios of these elements in the diet are important. Apparently bone formation can also be influenced by other dietary factors. For example, there is considerable controversy concerning the availability of phosphate from different dietary sources to animals. There also remains the need for re-evaluating the older recommendations relative to the phosphate and calcium requirements of animals in view of the more recent discoveries of heretofore unknown dietary essentials, such as vitamin B_{12}, which have promoted increased growth rates in animals. More recently there have been questions raised concerning the influence of antibiotics upon the skeletal development of animals.

In lieu of these facts it was very important that the investigations reported herein be conducted, to obtain more information concerning the dietary calcium and phosphorus requirements of the growing-finishing pig.

REVIEW OF LITERATURE

> No single answer has been agreed upon despite initiation over 100 years ago and intensive research during the last two decades concerning the constituition of bone mineral.
> —Armstrong, p. 699 (1952)

Body tissue of mesenchymal origin is broadly classified as connective tissue. Several types of tissue are included in this classification. However, this discussion will be confined to bone, the principle constituent tissue of the vertebrate endoskeleton.

As pointed out by Ham (1953), osteogenesis, or bone formation, requires the presence of cells known as osteoblasts. These cells have the poorly understood ability to produce the intercellular material of bone, by which they are eventually surrounded. When this occurs the osteoblasts lose their bone forming ability and are called osteocytes, or bone cells.

Due to the calcification of the intercellular substance, bone grows only appositionally. There is a proliferation and maturation of the epiphyseal cartilage cells. The intercellular portion of the cartilage becomes calcified, causing the cartilage cells in the area to die. They are then replaced by new-formed bone. In the presence of adequate calcium and phosphorus new bone normally calcifies immediately upon forming. In the case of inadequate levels of these two minerals the bone does not calcify and is commonly termed osteoid tissue. Such is the case when rickets occur in growing animals.

Microscopically, the intercellular material is seen to be honeycombed by a system of tiny canals. These canaliculi are passages through which nutrients are transported, from the many blood capillaries found in bone, to the osteocytes. This mechanism enables bone to have the characteristic ability to nourish cells, even though they are encased in calcified material.

Collagen, a fibrous protein, is the principle constituent of the intercellular material of bone. It is situated in a cement-like substance. The latter material has not been studied sufficiently to be completely identified. While the minerals involved in maintaining the structural form of bone are deposited in this cement-like material, between the collagenous fibers, the exact nature of this bone mineral is an extremely controversial subject.

Armstrong (1950, 1952) offers excellent reviews concerning the evolution of bone mineral concepts which have been suggested during the past 110 years. As emphasized by Armstrong (1950) there is little information at the present time of the complete composition of the unaltered bone mineral.

While there are differences of opinion concerning the anatomy of bone mineral, the majority of investigators currently concerned with bone chemistry apparently believe that the basic unit of bone mineral is hydroxyapatite, or an apatite-like structure; Hendricks (1952); Hodge (1952a) and Armstrong (1952). Evidence for the existence of such an entity was offered in the mid-twenties as a result of x-ray diffraction studies and has been substantiated many times since. For example, Robison (1951), using the electron microscope, reported collagen fibers present in the intercellular material, surrounded by amorphous material and inorganic hydroxyapatite crystals. The crystals were reported to be approximately 500 x 250 x 100 Angstrom units in size. He postulated that each bone crystal was comprised of cell units, each of which in turn was composed of two molecules of hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$.

In addition to its function in providing structural rigidity in vertebrates, bone also provides an easily accessible reserve of calcium and phosphorus which is drawn upon to maintain homeostasis of these two minerals in body fluids during periods of dietary inadequacy.

The metabolism of bone tissue has been demonstrated to be quite active and it has been shown that a continous exchange of phosphorus with the body fluids exists. Hodge (1952a) points out that radioisotopic studies have shown that phosphorus turnover in skeleton is so rapid that it would appear that entire bones might be replaced during short periods of time. However, in lieu of the rigidity and permanence of bone tissues he does not think this the correct interpretation of the results of the radioisotope studies and suggests that bone is composed of a labile and a stable portion. No attempt has been made to assign an anatomical location to the labile portion of bone. However, Neuman and Mulryan (1950) suggest that more labile bone is to be found in the epiphyseal and subperiosteal region than in the compact shaft. This is in harmony with the statement of Duckworth and Hill (1953) that uptake of radioactive calcium and phosphorus was much greater in the bone surrounding the Haversion canals than in older bone more distant from the caniculi.

The conception of the existance of the hydroxyapatite crystals has led some workers, Hendricks and Hill (1951), Hodge (1952) and Neuman (1950) to suggest that the surface of these crystals represent the labile portion of exchange in bone. They also suggest that the inner portion of the crystal is the more stable portion. Supporting evidence for this hypothesis was provided by Neuman and Mulyran (1952) who reported that exchange reactions of bone mineral occurred in two steps, an initial ionic exchange with ions in the surface of the bone crystal followed by a slower incorporation of the ions within the bone crystal.

Osseous tissue will also store elements normally foreign to the body, if they gain access to the circulatory system. A geologically widespread mineral element which at times is a hazard for livestock is fluorine. Hodge (1952b) states that fluoride absorbed into the body fluids is quickly removed by deposition in the skeleton or excretion in the urine. The magnitude of each of these metabolic pathways is reportedly in the neighborhood of 50 per cent of the intake. Fluoride concentration in the blood, body fluids, muscle and soft tissue amounts to no more than a few micrograms per cent.

Despite the incompleteness of the knowledge of bone composition, it has become evident that the metabolism of osseous tissue is affected by the adequacy or inadequacy of the diet in supplying the mineral nutrients to the animal organism. The influence of essential nutrients and other factors upon the metabolism of bone have been reviewed by Follis (1950, 1953). Duckworth and Hill (1953) have reviewed studies of bone composition as it reflects the nutritional status of animals. They point out that metabolic behavior of bone is not uniform throughout the skeleton or even within a single bone. They attribute much of the conflictory results from investigations concerned with storage of mineral elements in the skeleton to choice of osseous material chosen for study.

However, the skeleton contains the largest percentage of mineral in the body tissues, with some of the mineral elements being present as structural or functional parts of the skeleton. Other elements are found in bone tissue because they were present in the diet. The animal organism obtains these minerals from feeds, forages and mineral supplements.

Henry (1889, 1890) reported improved feed efficiency, increased total ash content and increased breaking strength of femurs of growing swine when bonemeal or hard wood ashes were added to a cornmeal basal ration. Further indications of the need for supplemental phosphorus for swine was provided by Burnett (1906, 1908, 1910) who reported greater growth and bone development in young pigs when a corn basal ration was supplemented with bonemeal.

Hart, McCollum and Fuller (1909) compared average daily gains and per cent of femur ash of pigs fed all plant rations with those receiving different inorganic phosphorus supplements and concluded that the growing pig was able to utilize phosphorus from plant or inorganic sources equally well. However, Forbes (1914) indicated that slower daily gains and poorer feed efficiency were realized when phytin phosphorus was fed to pigs, compared with those receiving various inorganic phosphorus supplements.

Other investigations involving rats, chickens and dogs have shown that species may differ in their ability to utilize phosphorus from plant sources; Boutwell et al. (1946); Spitzer and Phillips (1945); Gillis, Norris and Heuser (1953); Singsen and Mitchell (1944) and Mellanby (1944).

Robison (1926) using pigs of smaller initial weight than those employed by the earlier workers compared the value of several phosphorus supplements in mineral mixtures for swine. It is to be noted that there was a constant proportion of the different supplements included in the experimental rations, rather than a constant level of elemental phosphorus from the different supplements. Therefore, clear-cut conclusions could not be elucidated.

Further comparative studies of the value of different calcium and phosphorus supplements for growing swine were conducted by Mitchell et al. (1937). They employed a paired feeding technique to compare the value of different supplements when added to a corn-soybean oil meal basal ration. It was concluded that a simple mineral mixture of salt and steamed bonemeal was as satisfactory as more complex mixtures under their conditions. They also reported dicalcium phosphate and steamed bonemeal to be of comparable value as phosphorus supplements for swine when added to the calcium-deficient basal ration.

In a more recent investigation, Shrewsbury and Vestal (1945) compared steamed bonemeal, defluorinated phosphate, rock phosphate and superphosphate when added to a corn-soybean oil meal ration for pigs in drylot. A calcium-phosphorus ratio of 1.5:1 was used with the phosphorus level maintained at 0.43 per cent of the ration. They reported superior bone quality and rate of gain from the pigs fed steamed bonemeal and superphosphate as compared with those fed the other two supplements. These were reportedly unable to relate dietary fluorine content with their experimental results.

A relatively new product has been offered during the last 15 years for use as a phosphorus supplement for livestock. The accumulation of soft phosphate with colloidal clay, the residual by-product of the rock phosphate mining industry of North Central Florida, has resulted in a large potential source of phosphorus for feed and fertilizer use.

Considerable controversy has existed concerning the value of this material as a phosphorus supplement for poultry. Miller and Joukovsky (1953), Grau and Zweigert (1954) and Gillis, Norris and Heuser (1954), using growth response and bone calcification in poultry as criteria, reported that the biological value of soft phosphate with colloidal clay was not equal to that of dicalcium phosphate or steamed bonemeal.

Gobble and Miller (1953) and Gobble, Miller and Sherritt (1954) observed no significant difference in rate of gain, feed efficiency, blood serum inorganic phosphorus and per cent of ash of phosphorus in the moisture-free bone between groups of swine fed dicalcium phosphate and those fed colloidal clay. The latter supplement contains variable quantities of fluorine, but these investigators stated that no gross symptoms of fluorosis were observed in swine receiving this product.

According to Ammerman et al. (1954) there was no significant difference in the utilization of phosphorus from colloidal clay, steamed bonemeal and two different dicalcium phosphates by yearling steers. This study employed the short-term balance technique.

There have been recent reports in the literature that antibiotics may have an affect upon the utilization of some of the minerals by poultry. Ross and Yacowitz (1954) using growth response and tibia ash content as criteria, concluded that penicillin enhanced bone calcification in chicks, if adequate vitamin D were present in the ration. Linblad, Slinger and Motzok (1954) on the other hand, compared various combinations of calcium and phosphorus with and without aureomycin, and reported that the more inadequate the level of dietary calcium and phosphorus the greater the response to aureomycin. They also concluded that aureomycin did not alter the requirements for these two minerals by female chicks, but did increase the phosphorus needs of chick.

Investigations concerned with determining the optimum level and ratio of these two minerals for swine, with one exception, have been conducted prior to the wide use of antibiotics in swine rations. These earlier investigations have been reviewed by Roberts (1953) and will not be further discussed.

The only currently available investigations concerned with calcium and phosphorus requirements of growing swine fed antibiotic-supplemented rations is that of Roberts (1953). In his investigations, Roberts employed a seven by seven factorial experimental design. Rations containing 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 and 0.8 per cent each of calcium and phosphorus were fed to swine, with the results suggesting the minimum dietary requirement of each of the two minerals to be 0.4 per cent of the ration. However, Roberts was not able to define the dietary requirement of these elements for the growing pig on the basis of the data collected.

INVESTIGATION

Objectives

It was the purpose of these experiments to determine (1) the level of calcium and phosphorus which would insure the optimum rate of gain and skeletal development in the growing-finishing pig, (2) the ability of growing swine to utilize phosphorus of plant origin, (3) the effect of chlortetracycline (aureomycin HCl) upon the utilization of phosphorus by the growing pig, and (4) the comparative nutritional value of phosphorus from steamed bonemeal, soft phosphate with colloidal clay and dicalcium phosphate for growing swine.

Experimental Techniques

The research reported herein was conducted as a series of three experiments, recorded by the Iowa State Experiment Station as Swine Nutrition Experiments 593, 605 and 605-A.

Experiment 593 was designed to study the utilization by swine of phosphorus from plant material and from various high phosphorus supplements and to determine the affect of chlortetracycline upon the utilization of this phosphorus. Experiments 605 and 605-A were concerned with the re-evaluation of calcium and phosphorus needs of growing-finishing swine. In addition, when the results of experiments 605 and 605-A are discussed, they will be compared to and discussed in conjunction with the results of experiments 557-1 and 557-2, reported by Roberts (1953).

Experiment 593

The experimental design of this randomized block experiment is shown in Figure 1. There were two replications, each of which contained eighteen pens, or ration treatments. These are outlined in the figure by the dotted lines. Two barrow and two female pigs were placed in each pen, with a total of one hundred and forty-four weanling pigs of Poland China x Landrace x Duroc breeding used. The ration treatments were allotted randomly to pens within replication, and the pigs were allotted at random to the treatments by weight outcome groups within sex, within replication. Prior to placement on the experimental rations all pigs were wormed with sodium fluoride, sprayed with benzene hexachloride and dipped in lime sulfur. They were confined indoors on concrete and bedded with wood shavings. The pens were cleaned daily. Each pig was removed from the experiment when it reached a liveweight of 200 pounds. Body weights and feed consumption were determined every two weeks.

One animal of each sex was chosen from each pen, by pre-experimental randomized selection, to be slaughtered when it reached the live weight of 200 pounds. Both femur bones of each of the carcasses were analyzed for breaking strength, ash content and phosphorus, calcium, sodium, potassium, magnesium and fluorine content of the ash. The breaking strength and ash content of the femurs was determined by the method described by Roberts (1953). Four hundred milligrams of ash were placed in a 200 ml. volumetric flask, and treated with 5 ml. of concentrated HCl. When the bone ash was in solution distilled water was added to bring the

Figure 1. Experiment 593. Experimental design.

	SOURCE OF PHOSPHORUS								
	PLANT PHOSPHORUS			STEAMED BONEMEAL		COLLOIDAL CLAY		DICALCIUM PHOSPHATE	
P FROM SUPPLEMENT (%) →	0.00	0.15	0.30	0.18	0.30	0.18	0.30	0.18	0.30
P FROM PLANT SOURCE (%) →	0.50	0.35	0.20	0.32	0.20	0.32	0.20	0.32	0.20
REPLICATION 1/									
NO CHLORTETRACYCLINE 1									
NO CHLORTETRACYCLINE 2									
5 MG CHLORTETRACYCLINE 1									
5 MG CHLORTETRACYCLINE 2									

1/ TWO MALES AND TWO FEMALES PER PEN.

mixture to volume. The different ash analyses were conducted upon this solution. Phosphorus content of the ash was determined using the method of Fiske and Subbarow (1925). The calcium content of the femur ash was determined both chemically, using the procedure of Kramer and Tisdall (1921) as modified by Tisdall (1923) and Clark and Collip (1925), and by flame spectrophotometric analysis. Potassium, sodium and magnesium content of the ash was determined by flame spectrophotometric analysis. Fluorine determinations on both the bones and feed were conducted by a commercial laboratory.

The flame spectrophotometer is designed to measure the intensity of emission of a given wave length when an element is burned in a hydrogen and oxygen gas flame. The solution containing the element is passed through the capillary at a uniform rate at constant pressure. It is commonly assumed that if the physical characteristics of the unknown solution and standard solution are similar the rate of introduction will be similar and the flame intensity can be directly related to the concentration of the element in question. It was with these facts in mind that the present flame spectrophotometric determinations were conducted.

In lieu of the known interferences which elements may express in flame analysis, Parks, Johnson and Lykken (1948) and Wallace et al. (1951), standard curves for the flame photometer analysis of bone ash were calibrated by analyzing synthetic bone solutions containing quantities of calcium, phosphorus, potassium, sodium and magnesium representative of the composition of bone reported by Gabriel (1894).

While the analytical procedures he used may not have been comparable with current techniques, it was assumed that the analyses reported were representative of the average chemical composition of bone tissue.

The bone solution was synthesized by bringing together equal volumes of solutions containing phosphorus, calcium, potassium, sodium or magnesium in quantities representing the bone ash composition reported by Gabriel (1894). Five times the required level of the different elements was placed in their respective solutions to allow for dilution when the five solutions were combined.

In order to calibrate a standard curve for potassium, magnesium or sodium, the element in question was replaced with an equivalent volume of distilled water or solutions containing known quantities of the element. As seen in Figures 2, 3 and 4, the per cent of transmission of each of these elements was considerably lower in the synthetic mixtures as compared with the plain mixtures. The latter consisted of the same concentrations of only the element in question in double distilled water. In the case of calcium, a standard solution was obtained by a composite of five femur ash solutions for which the calcium content had been determined by the chemical procedure.

The instrument used in the flame spectrophotographic analysis was the Beckman Model DU Spectrophotometer with the Model 9200 flame attachment. The settings used to determine the different elements are shown in Table 1.

Table 1. Settings used in determining calcium, potassium, magnesium and sodium content of femur ash

Element	Wave length	Sensitivity[a]	Slit width	Photo tube
Calcium	554	$\frac{1}{2}$	0.15	blue
Potassium	766	$\frac{1}{2}$	0.10	red
Magnesium	383	$\frac{1}{2}$	0.50	blue
Sodium	589	Clockwise	0.15	blue

[a]Sensitivity knob setting between extreme anti-clockwise and clockwise positions

Blood samples were taken from the coccygeal artery when each animal reached 100 and 200 pounds, live weight. Duplicate inorganic phosphate determinations were made using the procedure of Zilversmit and Davis (1950).

The experimental rations, presented in Table 2, were fed to the animal both with and without chlortetracycline. The rations were formulated so that each contained the same calcium and phosphorus level and ratio. The per cent of calcium and phosphorus used in the experimental rations were 0.7 and 0.5 respectively, since Roberts (1953) reported that these levels appeared to give best results with antibiotic-supplemented rations for growing swine. To eliminate possible effect due to the method of production of the commercial phosphorus supplements, steamed bonemeal, soft phosphate with colloidal clay and dicalcium phosphate were obtained from three different producers. Equal parts of these were then blended thoroughly before incorporation into the experimental rations.

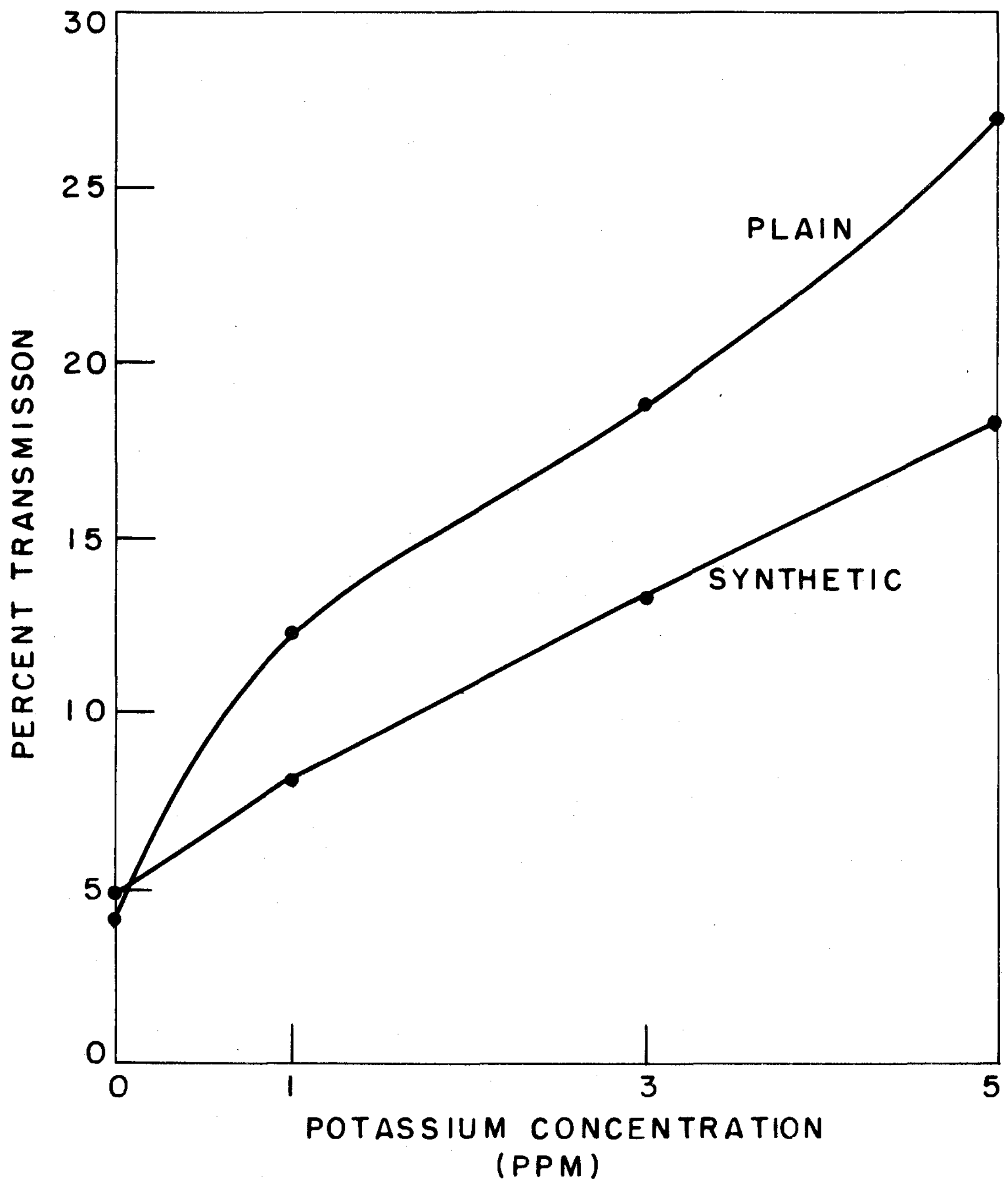

Figure 2. Standard curve for flame spectrophotometric determination of potassium content of bone ash

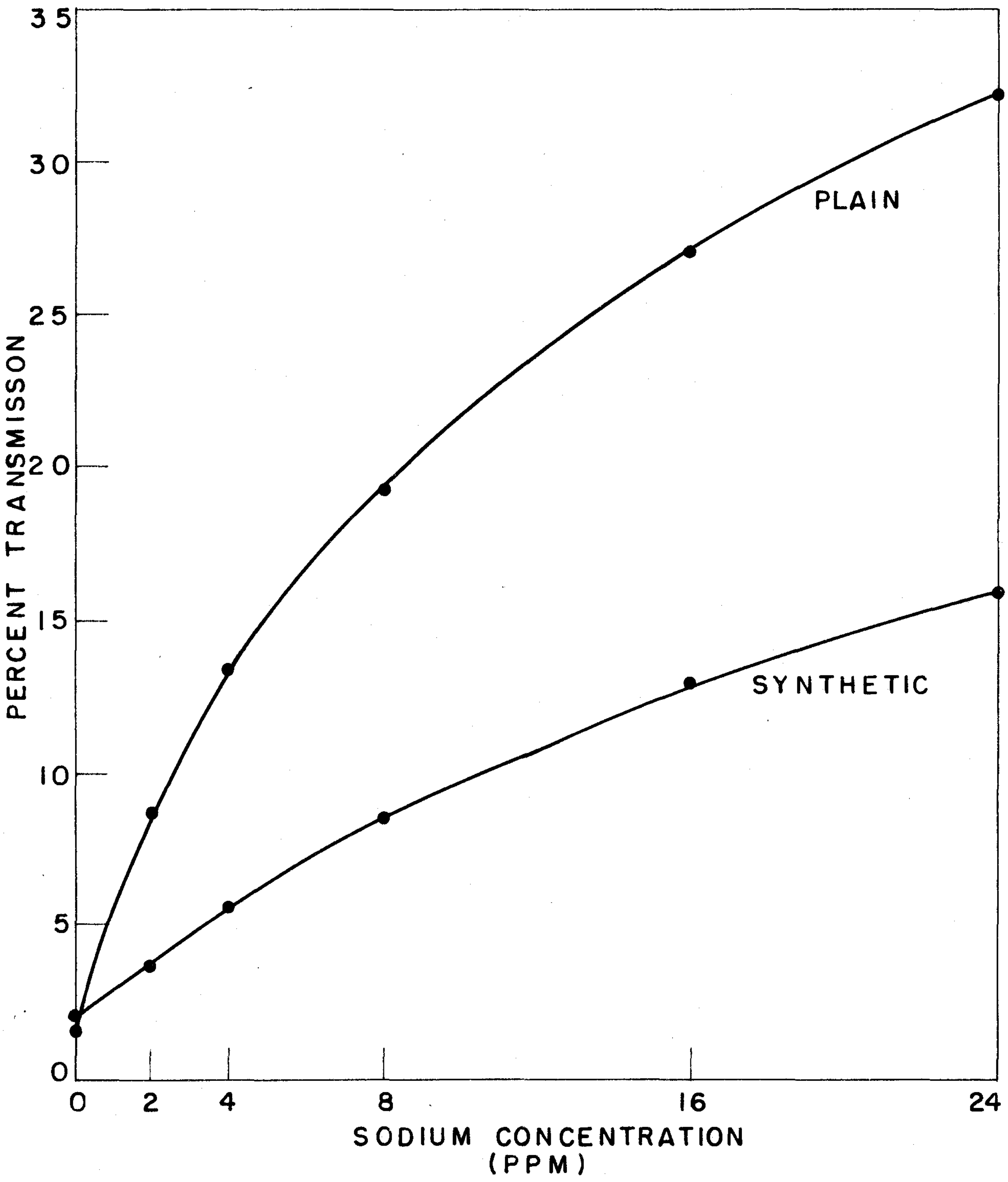

Figure 3. Standard curve for flame spectrophotometric determination of sodium content of bone ash

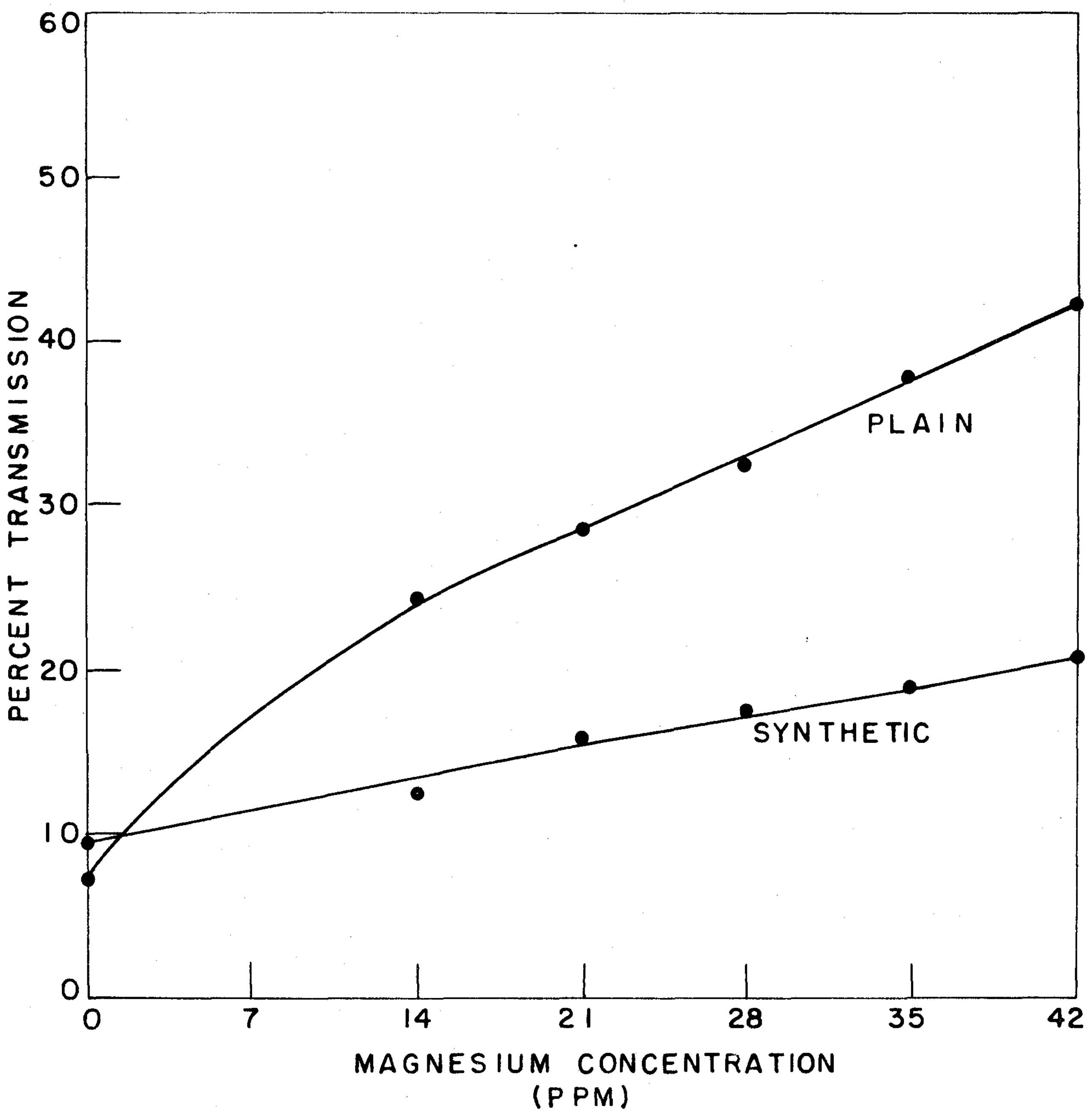

Figure 4. Standard curve for flame spectrophotometric determination of magnesium content of bone ash

Table 2. Experiment 593. Composition of experimental rations

	Source of phosphorus								
	Plant phosphorus			Steamed bonemeal[a]		Colloidal clay[b]		Dicalcium phosphate[c]	
P from supplement (%)	0.00	0.15	0.30	0.18	0.30	0.18	0.30	0.18	0.30
P from plant source (%)	0.50	0.35	0.20	0.32	0.20	0.32	0.20	0.32	0.20
<u>Ingredients</u>									
Wheat bran	19.00	4.00	—	—	—	—	—	—	—
Ground yellow corn	60.85	67.55	—	75.40	—	74.40	—	75.60	—
Brewers' grits	—	—	61.75	—	69.95	—	68.95	—	70.95
Oat hulls	—	3.50	8.00	—	—	—	—	—	—
Corn oil (crude)	—	0.40	2.65	—	2.40	—	2.40	—	2.40
Solvent soybean oil meal	16.00	20.20	23.00	20.00	22.50	20.30	21.50	20.00	22.00
Trace minerals[d]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Iodized salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Calcium carbonate	1.55	0.95	0.35	0.50	—	0.55	—	0.85	—
Phosphorus carrier	—	0.80	1.65	1.50	2.55	2.15	3.55	0.95	1.65
Vitamin premix[e]	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

[a]Supplied by Darling and Company, Swift and Company and Armour and Company
[b]Supplied by Kellogg Company, Seaboard Sales Company and Loncala Phosphate Company
[c]Supplied by Shea Chemical Corporation, Victor Chemical Company and Monsanto Chemical Company
[d]See Table 4
[e]See Table 3

Each phosphate supplement was tested at two different levels. The per cent of each phosphorus supplement needed to supply these levels is presented in Table 2.

Wheat bran was used to increase the plant phosphorus for testing the availability of phytin phosphorus. Constant fiber levels were maintained by adding oat hulls where needed. In determining the ability of the pig to utilize phosphorus from plant sources (phytin phosphorus), dicalcium phosphate was arbitrarily chosen as the inorganic phosphate supplement to which it was to be compared.

The protein level of the experimental rations was maintained at 16 per cent throughout the entire experimental period. A vitamin premix (Table 3) as well as a trace mineral premix (Table 4) was added to the rations to supply the vitamins and trace minerals in amounts considered optimum for growing swine.

The rations were fed *ad libitum* and water was provided by automatic water cups. The feeders and waterers were checked daily to assure proper functioning.

The data were analyzed statistically according to the plans in Tables 25, 26 and 27 of the appendix, with all stated levels of statistical significance at the $P = .05$ level. The statistical analysis of the several measurements studied has been carried out in the main in two parts: (1) among levels of plant phosphorus and (2) among the three phosphorus, namely steamed bonemeal, colloidal clay and dicalcium phosphate. The average effect of the whole experiment

Table 3. Experiment 593. Amount of vitamins and antibiotics added per pound of complete ration[a]

Ingredients	Added per pound of ration
Vitamin A, I.U.[b]	3000.0
Vitamin D_2, I.U.[c]	200.0
Menadione, mg.	0.5
Alpha-tocopherol acetate, mg.	1.0
Thiamine hydrochloride, mg.	1.5
Riboflavin, mg.	1.5
Niacin, mg.	20.0
Calcium pantothenate, mg.	6.0
Choline chloride, mg.	250.0
Pyridoxine hydrochloride, mg.	1.5
Folic acid, mg.	0.5
Biotin, mg.	0.1
Vitamin B_{12}, mcg.[d]	5.0
Chlortetracycline, mg.[e]	5.0

[a]Vitamins were added to the ration in a soybean oil meal premix
[b]Supplied as stabalized vitamin A acetate, Nopco Chemical Company
[c]Supplied as type 9-F irradiated yeast, Standard Brands, Incorporated
[d]Supplied as vitamin B_{12} feeding supplement, Merck and Company, Incorporated
[e]Supplied as crystalline aureomycin HCl, Lederle Laboratories Division

was considered, however, in the case of antibiotics, sex and weight influence.

Experiments 605 and 605-A

As previously stated, the purpose of these two experiments was to re-evaluate the calcium and phosphorus requirement of growing swine. Levels of calcium fed ranged from 0.2 through 0.8 per cent inclusive and phosphorus from 0.2 through 0.7 per cent. The design of the experiment is presented in Figure 5, with the experimental treatments outlined by the

Table 4. Trace mineral premix[a]

Element	Form	Per cent in premix
Mn	$MnSO_4 \cdot 4H_2O$	5.90
Fe	$FeSO_4 \cdot 7H_2O$	7.00
Cu	$CuSO_4 \cdot 5H_2O$	0.48
Co	$CoSO_4 \cdot H_2O$	0.16
Zn	$ZnSO_4 \cdot H_2O$	0.45
K	K_2SO_4	0.75
Ca	$CaCO_3$	14.20

[a]Contributed the following p.p.m. to the ration: Fe, 70; Cu, 4.8; Co, 1.6; Mn, 59; Zn, 4.4; and K, 76

heavier line. While it was thought that the most satisfactory calcium-phosphorus ratio was between 1:1 and 2:1, it was felt desirable to provide emphasis to this thesis. Therefore, ratios of 0.5:1 through 3:1 were included in the experimental treatments. The calcium-phosphorus ratios of the various ration treatments are presented in their designated square.

Experiments 605 and 605-A were duplicated in experimental procedure except for two factors. Although each was conducted on concrete drylot, Experiment 605 was conducted inside during the winter of 1953-54, and Experiment 605-A outisde during the summer of 1954. This was for the purpose of determining whether the requirements of swine for these two minerals varied with season. The other principle difference was that there was 1 female and 2 male pigs per ration treatment in Experiment 605, and the reverse of this per lot during Experiment 605-A. This provided an equal number of male and female pigs per treatment, within weight outcome groups. Otherwise, the experiments were duplicated as near as possible and will be described as one, in regard to experimental procedure.

Weanling pigs of Poland China x Landrace x Duroc breeding were allotted randomly by weight outcome groups within sex within experiments to each of the twenty-five ration treatments. Prior to allotment the pigs were wormed with sodium fluoride, sprayed with benzene hexachloride and dipped in lime sulphur.

It was desired to determine the effect of the experimental treatments at different ages. By pre-experimental randomized selection one pig was removed for slaughter when it reached 100 pounds live weight, one at 150 pounds and the last when it reached 200 pounds in weight. The experimental lots were weighed every two weeks and when each pig reached its terminating weight. After the pigs were slaughtered, the carcasses were treated as described by Roberts (1953). Both femurs were removed from each carcass and analyzed for breaking strength, ash, fat, and water content. Phosphorus, calcium, sodium, magnesium and potassium content of the ash were also determined. The bone analysis was conducted as previously described.

The experimental rations were calculated to conform as nearly as possible to those used by Roberts (1953). However, brewers' corn grits were substituted for ground yellow corn when low-phosphorus rations were

Figure 5. Experiments 605 and 605-A. Experimental design.

CALCIUM AND PHOSPHORUS REQUIREMENTS OF G-F SWINE
EXPERIMENTAL DESIGN

CALCIUM (%)

PHOSPHORUS %

%	0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	1.0	1.5	2.0	2.5	3.0		
0.3	0.67	1.0	1.3	1.67	2.0		
0.4	0.5	0.75	1.0	1.25	1.50	1.75	2.0
0.5				1.0	1.2	1.4	1.6
0.6					1.0	1.17	1.13
0.7						1.0	

required, rather than pearled corn starch. When brewers' grits were used, a constant fat level was maintained by the addition of crude corn oil. The levels of calcium and phosphorus were changed by adjusting the amounts of corn, brewers' grits, solvent extracted soybean oil meal, calcium carbonate and monocalcium phosphate in the ration. The protein level was maintained at 16 per cent from the initiation of the experiments until the lot reached an average weight of 75 pounds. The protein level was then reduced to 13 per cent until a lot average of 150 pounds was reached. It was then reduced to 10 per cent until the end of the experiment. When necessary, the protein level was altered by varying the proportions of soybean oil meal, ground yellow corn and/or brewers' corn grits. The composition of the vitamin-antibiotic premix which was added to the ration is shown in Table 5. The trace mineral premix was the same as that used in experiment 593 and was included in the rations at the rate of 0.1 per cent of the ration. The experimental rations also contained 0.5 per cent of iodized salt. The ingredient composition of the 16 per cent protein rations used in Experiments 605 and 605-A are shown in Tables 6 and 7, respectively.

Feeding was *ad libitum* and water was again provided by automatic water cups. They were checked daily to assure proper functioning. Feed weights were obtained every two weeks and when pigs were removed from the experiment, with waste feed being subtracted from the amounts charged against each lot.

Owing to large and inconsistent variation between trials, Roberts (1953) subjected each of his experiments to a separate statistical

Table 5. Experiments 605 and 605-A. Amounts of vitamins and antibiotics added per pound of complete ration[a]

Ingredients	Added per pound of ration
Vitamin A, I.U.[b]	2000.0
Vitamin D_2, I.U.[c]	400.0
Menadione, mg.	0.5
Alpha-tocopherol acetate, mg.	1.5
Thiamin hydrochloride, mg.	1.5
Riboflavin, mg.	0.9
Niacin, mg.	11.0
Calcium pantothenate, mg.	2.0
Choline chloride, mg.	50.0
Pyridoxine hydrochloride, mg.	1.5
Folic acid, mg.	0.5
Biotin, mg.	0.1
Para-amino-benzoic acid, mg.	0.5
Vitamin B_{12}, mcg.[d]	5.0
Chlortetracycline mg.[e]	5.0

[a]Vitamins were added to the ration in a soybean oil meal premix

[b]Supplied as stabalized vitamin A acetate, Nopco Chemical Company

[c]Supplied as type 9-F irradiated yeast, Standard Brands, Incorporated

[d]Supplied as vitamin B_{12} feeding supplement, Merck and Company, Incorporated

[e]Supplied as crystalline aureomycin HCl, Lederle Laboratories Division

analysis. These inconsistencies prevented him from defining the growing-finishing pigs' requirements for these two elements. They were also suggestive of possible seasonal effects upon the results he obtained.

Since this condition existed then and was encountered in experiments 605 and 605-A, it was thought best to combine the results of the four experiments for final statistical analysis. This procedure will tend to remove the effect of peculiarities in pig performance and provide a true

Table 6. Experiment 605. Composition of sixteen per cent protein rations[a]

(per cent)

Ca-P content of ration (%)	Brewers' grits	Ground yellow corn	Solvent soybean oil meal	Corn oil	Mono-calcium phosphate	Calcium carbonate
0.2-0.2	74.5	--	21.0	2.5	0.1	0.3
0.3-0.2	74.3	--	21.0	2.5	0.1	0.5
0.4-0.2	74.0	--	21.0	2.5	0.1	0.8
0.5-0.2	73.8	--	21.0	2.5	0.1	1.0
0.6-0.2	73.5	--	21.0	2.5	0.1	1.3
0.2-0.3	28.9	50.0	19.0	--	0.3	0.2
0.3-0.3	29.0	50.0	18.7	--	0.3	0.4
0.4-0.3	28.4	50.0	19.0	--	0.3	0.7
0.5-0.3	24.7	53.2	19.3	--	0.3	0.9
0.6-0.3	24.4	53.2	19.3	--	0.3	1.2
0.2-0.4	--	79.0	18.8	--	0.6	--
0.3-0.4	--	79.0	18.5	--	0.6	0.3
0.4-0.4	--	78.7	18.5	--	0.7	0.5
0.5-0.4	--	78.5	18.5	--	0.6	0.8
0.6-0.4	--	78.2	18.5	--	0.7	1.0
0.7-0.4	--	77.8	18.7	--	0.6	1.3
0.8-0.4	--	77.5	18.7	--	0.7	1.5
0.5-0.5	--	78.0	18.7	--	1.2	0.5
0.6-0.5	--	77.7	18.8	--	1.1	0.8
0.7-0.5	--	77.4	18.8	--	1.2	1.0
0.8-0.5	--	77.2	18.8	--	1.1	1.3
0.6-0.6	--	77.2	19.0	--	1.6	0.6
0.7-0.6	--	77.0	18.9	--	1.7	0.8
0.8-0.6	--	76.8	18.9	--	1.6	1.1
0.7-0.7	--	76.7	19.0	--	2.1	0.6

[a]Each ration contained 1.0 per cent vitamin premix (Table 5), 0.5 per cent iodized salt and 0.1 per cent trace mineral mix (Table 4)

Table 7. Experiment 605-A. Composition of sixteen per cent protein ration[a]

(per cent)

Ca-P content of ration (%)	Brewers' grits	Ground yellow corn	Solvent soybean oil meal	Corn oil	Mono-calcium phosphate	Calcium carbonate
0.2-0.2	76.5	—	19.0	2.5	0.1	0.3
0.3-0.2	76.3	—	19.0	2.5	0.1	0.5
0.4-0.2	76.0	—	19.0	2.5	0.1	0.8
0.5-0.2	75.6	—	19.2	2.5	0.1	1.0
0.6-0.2	75.3	—	19.2	2.5	0.1	1.3
0.2-0.3	28.9	50.5	18.5	—	0.3	0.2
0.3-0.3	29.0	50.0	18.7	—	0.3	0.4
0.4-0.3	28.4	50.5	18.5	—	0.3	0.7
0.5-0.3	25.0	53.4	18.8	—	0.3	0.9
0.6-0.3	24.7	53.4	18.8	—	0.3	1.2
0.2-0.4	—	79.0	18.8	—	0.6	—
0.3-0.4	—	79.0	18.5	—	0.6	0.3
0.4-0.4	—	78.7	18.5	—	0.7	0.5
0.5-0.4	—	78.5	18.5	—	0.6	0.8
0.6-0.4	—	78.2	18.5	—	0.7	1.0
0.7-0.4	—	77.8	18.7	—	0.6	1.3
0.8-0.4	—	77.5	18.7	—	0.7	1.5
0.5-0.5	—	78.0	18.7	—	1.2	0.5
0.6-0.5	—	77.7	18.8	—	1.1	0.8
0.7-0.5	—	77.4	18.8	—	1.2	1.0
0.8-0.5	—	77.2	18.8	—	1.1	1.3
0.6-0.6	—	77.2	19.0	—	1.6	0.6
0.7-0.6	—	77.0	18.9	—	1.7	0.8
0.8-0.6	—	76.8	18.9	—	1.6	1.1
0.7-0.7	—	76.7	19.0	—	2.1	0.6

[a]Each ration contained 1.0 per cent vitamin premix (Table 5), 0.5 per cent iodized salt and 0.1 per cent trace mineral mix (Table 4)

perspective regarding the response which should be expected from a pig which is fed a given dietary level of calcium and phosphorus.

When the data for these four experiments were pooled, it was found that there was no season and ration interaction. This enabled the trials to be considered replications, statistically. The multiple regression analysis of rate of gain, breaking strength of femurs and per cent ash of femurs was conducted for all three weight groups. The multiple regression model used was $Y = a + b_1Ca + b_2P + b_3Ca^2 + b_4P^2 + b_5CP$, where Y is the measure of response. Another multiple regression model was investigated ($Y = a + b_1Ca + b_2P + b_3\sqrt{Ca} + b_4\sqrt{P} + b_5\sqrt{CaP}$) and was found to add little to the analysis. Therefore the previously mentioned model, with the appropriate partial regression coefficients, was used to compute predicted values for rate of gain, breaking strength of femurs and ash content of femurs at any given dietary level of phosphorus and calcium. This choice of models was made due to greater ease of computation of the predicted values, in lieu of the similarities of final results.

These three criteria were also statistically analyzed according to the plan in Table 28 of the appendix. Femur weight, water content, fat content and phosphorus, calcium, magnesium, sodium and potassium content of femur ash were statistically analyzed according to the plan in Tables 29 and 30 of the appendix.

Results

Experiment 593

It was desired to determine if the treatment variables expressed dissimilar responses at different periods of growth in the pig. Therefore the results of this experiment are presented for two periods of growth, as indicated by body weight.

Period from 25 to 100 pounds body weight. While some additional response was obtained from the inclusion of chlortetracycline in the ration, the data (Table 8) show no significant differences in the rate of gain, average feed efficiency or daily feed intake.

The source of phosphorus supplement had no significant effect on either average daily feed intake or feed efficiency. However, the average daily gain was significantly reduced in those pigs receiving colloidal clay compared with those fed steamed bonemeal or dicalcium phosphate. Pigs receiving the higher levels of phosphorus from the inorganic phosphorus supplements ate significantly less feed per day and required significantly less feed per pound of gain (hereafter referred to as feed efficiency) than those receiving more of their phosphorus from plant sources. (Table 8)

As the level of phosphorus from an inorganic source (dicalcium phosphate) was increased from 0.0 to 0.3 per cent of the total ration there was a significant linear effect on increasing rate of gain and a significant quadratic effect on increasing average daily feed intake. However, there was no statistically significant effect upon feed

Table 8. Experiment 593. Summary of average daily gain, daily feed consumption and feed required per pound of gain, 25 - 100 pounds

(lbs.)

Ration treatment		No. pigs	Average daily gain	Average feed intake	Average feed/lb. gain
No antibiotics		72	1.37	3.5	2.59
5 mg. antibiotic		72	1.41	3.7	2.63
Steamed bonemeal					
Inorg. P.	Plant P.				
0.18[a]	0.32	16	1.43	3.8	2.66
0.30	0.20	16	1.51	3.6	2.37
	Av.	32	1.47	3.7	2.52
Dicalcium phosphate					
Inorg. P.	Plant P.				
0.18	0.32	16	1.48	3.9	2.61
0.30	0.20	16	1.42	3.7	2.58
	Av.	32	1.45	3.8	2.59
Colloidal clay					
Inorg. P.	Plant P.				
0.18	0.32	16	1.33	3.8	2.82
0.30	0.20	16	1.31	3.3	2.52
	Av.	32	1.32[b]	3.5	2.67
Inorg. P.	Plant P.				
0.18	0.32	48	1.41	3.8	2.70
0.30	0.20	48	1.42	3.5[c]	2.49[c]
Levels of plant P.					
0.50		16	1.18[c]	3.1[d]	2.68
0.35		16	1.38	3.8	2.78
0.20		16	1.43	3.6	2.50

[a]Per cent of total ration

[b]Average effect of source of P. significant at P = .05 or less

[c]Linear effect of level of inorganic P. significant at P = .05 or less

[d]Quadratic effect of level of P. from plant sources significant at P = .05 or less.

efficiency as the per cent of phosphorus from plant sources was decreased in the ration.

Analyses of the blood samples taken when the pigs were 100 pounds in weight are shown in Table 9. Considerable hemolysis occurred in all blood samples. The effects of hemolysis on the results of these analyses were not evaluated. No significant effect of ration treatments on the blood data was discernable during this period.

<u>Period from 25 - 200 pounds of body weight</u>. In contrast to the results of the earlier period, there was, as shown in Table 10, a small but significant increase in average daily gain when chlortetracycline was included in the rations. The differences in feed intake and feed efficiency resulting from antibiotic feeding were extremely small.

The pigs receiving colloidal clay gained significantly slower than those receiving either steamed bonemeal or dicalcium phosphate, but there was little difference in the degree of weight gain response of the pigs receiving the latter two supplements. The daily feed intake of the colloidal clay fed pigs was significantly less than for pigs fed dicalcium phosphate. The difference in the daily feed intake between the colloidal clay and bonemeal groups was just short of significance at the P = .05 level.

The pigs receiving steamed bonemeal demonstrated a significantly better feed efficiency than those fed colloidal clay. While less feed was also required per pound of gain by the pigs fed dicalcium phosphate, the difference was not statistically significant at the P = .05 level.

When the average level of phosphorus furnished in the ration by the

Table 9. Experiment 593. Summary of blood serum inorganic phosphorus (milligrams per cent)

Ration treatment		No. pigs	100 lb. pigs	200 lb. pigs	Average
No antibiotic		72	12.2	11.1	11.6
5 mg. antibiotic		72	11.8	10.8	11.3
Steamed bonemeal					
Inorg. P.	Plant P.				
0.18[a]	0.32	16	12.0	11.1	11.5
0.30	0.20	16	12.0	10.8	11.4
	Av.	32	12.0	10.9	11.5
Dicalcium phosphate					
Inorg. P.	Plant P.				
0.18	0.32	16	12.3	11.2	11.7
0.30	0.20	16	11.7	11.6	11.6
	Av.	32	12.0	11.4	11.7
Colloidal clay					
Inorg. P.	Plant P.				
0.18	0.32	16	12.3	11.9	12.1
0.30	0.20	16	13.0	9.8	11.4
	Av.	32	12.6	10.8	11.7
Inorg. P.	Plant P.				
0.18	0.32	48	12.2	11.4	11.8
0.30	0.20	48	12.2	10.7	11.5
Levels of plant P.					
0.50		16	11.2	9.8	10.5[b]
0.35		16	11.3	11.1	11.2
0.20		16	12.0	11.7	11.8
Sex					
Barrows		72	12.0	10.8	11.4
Sows		72	12.0	11.2	11.6
	Av.	144	12.0	11.0[c]	

[a]Per cent of total ration
[b]Linear effect of plant P. significant at P = .05 or less
[c]Effect of age significant at P = .05 or less

Table 10. Experiment 593. Summary of average daily gain, daily feed consumption and feed required per pound of gain, 25 - 200 pounds

(lbs.)

Ration treatment		No. pigs	Average daily gain	Average feed intake	Average feed/lb. gain
No antibiotics		72	1.54	5.0	3.27
5 mg. antibiotics		72	1.60[a]	5.1	3.22
Steamed bonemeal					
Inorg. P.	Plant P.				
0.18[b]	0.32	16	1.64	5.3	3.26
0.30	0.20	16	1.66	4.8	2.90
	Av.	32	1.65	5.0	3.08
Dicalcium phosphate					
Inorg. P.	Plant P.				
0.18	0.32	16	1.59	5.3	3.34
0.30	0.20	16	1.66	4.9	2.95
	Av.	32	1.63	5.1	3.14
Colloidal clay					
Inorg. P.	Plant P.				
0.18	0.32	16	1.50	5.2	3.45
0.30	0.20	16	1.42	4.4	3.10
	Av.	32	1.46[c]	4.8[c]	3.28[c]
Inorg. P.	Plant P.				
0.18	0.32	48	1.58	5.3	3.35
0.30	0.20	48	1.58	4.7[d]	2.98[d]
Levels of plant P.					
0.50		16	1.45[d]	5.3	3.66[d]
0.35		16	1.57	5.4	3.48
0.20		16	1.63	5.0	3.11

[a]Average effect of antibiotic significant at P = .05 or less
[b]Per cent of total ration
[c]Average effect of source of P. significant at P = .05 or less
[d]Linear effect of level of inorganic P. significant at P = .05 or less

three supplements was increased from 0.18 to 0.30 per cent there was no effect on the average rate of gain. However, the feed required per pound of gain and the average daily feed intake were significantly decreased.

Increasing the proportion of inorganic phosphorus in the rations resulted in a significant linear increase in average daily gains and improvement in feed efficiency for the pigs fed these rations.

As shown in Table 11, the breaking strength of the femurs of the pigs receiving steamed bonemeal was significantly higher than the average breaking strength of the femurs from pigs receiving either colloidal clay or dicalcium phosphate. However, there was no significant effect of steamed bonemeal, colloidal clay or dicalcium phosphate on the weight, water content or fat content of the femurs. Table 11 shows that as the level of plant phosphorus decreased in the ration there was a significant linear increase in fat content of the water-free femurs.

It was also noted that femurs from male pigs contained an average of 33.4 per cent of water as compared with 29.8 per cent in femurs from female pigs. This difference was significant at the $P = .01$ level.

There was a significant increase in the ash content of the femurs from the pigs receiving colloidal clay as compared with the pigs fed the other phosphorus supplements.

There was no significant difference in the phosphorus content of the femur ash resulting from any of the experimental phosphorus treatments. However, as shown in Table 12, there was a significantly higher phosphorus content in the femur ash from pigs receiving no antibiotic, as compared with those from pigs receiving chlortetracycline.

Table 11. Experiment 593. Summary of femur weight, breaking strength and water content of femurs, fat content of water-free femurs and ash content of water-free, fat-free femurs

Ration treatment		No. pigs	Femur wt. (lbs.)	Breaking strength (lbs./sq. in.)	Water (%)	Fat (%)	Ash content (%)
No antibiotics		36	216.5	1255	31.8	24.8	57.5
5 mg. antibiotics		36	224.0	1247	31.4	24.5	57.7
Steamed bonemeal							
Inorg. P.	Plant P.						
0.18[a]	0.32	8	228.7	1304	31.4	24.4	56.9
0.30	0.20	8	220.3	1366	30.9	23.7	58.5
	Av.	16	224.5	1335	31.2	24.0	57.7
Dicalcium phosphate							
Inorg. P.	Plant P.						
0.18	0.32	8	226.7	1299	32.4	24.2	57.1
0.30	0.20	8	219.6	1250	33.9	22.7	56.9
	Av.	16	223.1	1274	33.2	23.4	57.0
Colloidal clay							
Inorg. P.	Plant P.						
0.18	0.32	8	229.5	1170	31.1	26.6	58.2
0.30	0.20	8	214.2	1172	31.3	24.0	58.1
	Av.	16	221.8	1171[b]	31.2	25.3	58.2[b]
Inorg. P.	Plant P.						
0.18	0.32	24	228.3	1248	31.6	25.1	57.4
0.30	0.20	24	218.0	1263	32.3	23.5	57.8
Levels of plant P.							
0.50		8	203.6	1187	30.1	27.7[c]	57.2
0.35		8	221.2	1268	31.8	25.0	57.4
0.20		8	218.6	1245	31.2	23.6	58.3
Sex							
Barrows		36	220.4	1223	33.4[d]	24.4	57.3
Sows		36	220.1	1280	29.8	24.9	57.9

[a]Per cent of total ration
[b]Effect of sources of phosphorus significant at P = .05 or less
[c]Linear effect of level of inorganic P. significant at P = .05 or less
[d]Average effect of sex significant at P = .01 or less

The chemical determination of calcium in the femur ash revealed that the ash from pigs receiving colloidal clay was significantly higher in this element than was the ash from the other pigs of the experiment. As shown in Table 12, the chemical analysis revealed no significant difference of ash calcium content due to antibiotic supplementation or sex.

When the calcium content of the femur ash was determined by flame spectrophotometric analysis, it was found that femur ash from pigs receiving dicalcium phosphate was significantly higher in this element than was that from femurs of pigs receiving the other two phosphorus supplements. Also the data (Table 12) shows the femur ash from pigs receiving steamed bonemeal was significantly higher in calcium than was that from pigs receiving colloidal clay. The only other significant difference in calcium content of femur ash by this method was the higher level of this element in femur ash from male pigs as compared with that from females.

A comparison of the two procedures for determining the calcium content of the femur ash revealed that a negative correlation existed. When the individual pig was considered as the experimental unit, this correlation was significant at the $P = .05$ level. When the two pigs from the same pen were considered as the experimental unit the correlation was still negative, but was not statistically significant at this level.

There was no significant difference in magnesium content of femur ash of pigs due to treatment effect. However, the data (Table 12) show that the femur ash of male pigs was significantly higher in

Table 12. Experiment 593. Summary of phosphorus, calcium, potassium, magnesium and sodium content of femur ash

Ration treatment		No. pigs	P	Ca Chem. anal.	Ca Spectro. anal.	K[a]	Mg	Na
			(%)			(PPM)		
No antibiotics		36	18.9[b]	39.2	36.2	2.3	22.8	16.3
Antibiotic, 5 mg.		36	18.6	38.5	36.0	2.6	23.6	16.1
Steamed bonemeal								
Inorg. P.	**Plant P.**							
0.18[c]	0.32	8	18.7	36.9	35.9	2.3	22.8	16.2
0.30	0.20	8	18.9	37.1	35.9	2.4	23.2	15.6
	Av.	16	18.8	37.0	35.9	2.4	23.0	15.9
Dicalcium phosphate								
Inorg. P.	**Plant P.**							
0.18	0.32	8	19.0	38.9	36.5	2.7	22.6	16.5
0.30	0.20	8	18.9	36.9	38.9	3.0	23.8	15.9
	Av.	16	18.9	37.9	37.7	2.8	23.2	16.2
Colloidal clay								
Inorg. P.	**Plant P.**							
0.18	0.32	8	18.7	41.6	33.5	1.9	23.0	17.2
0.30	0.20	8	18.8	41.5	33.8	2.3	23.0	17.0
	Av.	16	18.8	41.6[d]	33.6[d]	2.1[d]	23.0	17.1[d]
Inorg. P.	**Plant P.**							
0.18	0.32	24	18.8	39.1	35.3	2.3	22.8	16.6
0.30	0.20	24	18.9	38.5	36.2	2.6	23.3	16.2
Levels of plant P.								
0.50		8	18.8	38.9	36.7	2.6	24.2	16.2
0.35		8	18.6	39.4	37.8	2.6	22.4	15.6
0.20		8	18.6	38.1	35.6	2.5	23.7	15.8
Sex								
Barrows		36	18.7	39.3	36.7[e]	—	25.2[e]	16.6
Sows		36	18.9	38.3	35.4	—	21.2	15.8

[a]Potassium values for male pigs only
[b]Average effect of antibiotic significant at P = .05 level
[c]Per cent of total ration
[d]Effect of source of phosphorus significant at P = .05 level
[e]Effect of sex significant at P = .05 level

magnesium content than was that from pigs of the opposite sex. Swine receiving dicalcium phosphate had significantly higher levels of potassium in their femur ash than did pigs fed colloidal clay. As shown in Table 12, there were no significant differences in the level of this element in femur ash due to including the antibiotic in the ration. Consistent, reproducible determinations of potassium were not possible for ash from the femurs of female pigs.

The data (Table 12) show that sodium content of bone was fairly constant. However, femur ash from pigs receiving colloidal clay was significantly higher in this element than femur ash from pigs receiving the other two supplements. There was no significant effect of antibiotic supplementation or sex.

As the fluorine content of the rations increased there was a corresponding increase in the fluorine content of the femur bones. The fluorine content of the rations and the femurs of pigs fed steamed bonemeal and dicalcium phosphate were similar. However, supplementation of the ration with colloidal clay increased the fluorine content of both the rations and the femurs of the pigs fed these rations.

A significant linear increase in inorganic serum phosphorus was observed as the amount of phosphorus from the plant sources was decreased from 0.5 to 0.2 per cent of the total ration and replaced by an equivalent amount of phosphorus from dicalcium phosphate. There was no other significant effect of ration treatment on serum inorganic phosphorus. There was also a significant decrease of serum inorganic phosphate as the age of the pig increased.

Experiments 605 and 605-A

The data for growth, feed and bone analysis, excluding calcium, potassium, sodium and magnesium of femur ash are presented in Tables 13 through 20. There were considerable inconsistencies in these response criteria from animals between experiments within treatment. Because of these inconsistencies, it was felt more desirable to pool the data for these criteria from experiments 605 and 605-A with that reported by Roberts (1953) for statistical treatment, rather than to treat each as a separate entity. Therefore, the data from experiments 605 and 605-A will not be discussed separately in any great detail.

However, weight gains were fairly satisfactory. This was true even when levels of calcium and phosphorus were fed which were considered to be inadequate to promote adequate growth response. While symptoms of skeletal abnormalities were evident in some instances, the experimental animals were generally thrifty.

The incidence of skeletal abnormalities was not as severe qualitatively or quantitatively as compared with the earlier findings of Roberts (1953). There were nineteen cases of stiffness recorded during experiment 605, while the pigs in experiment 605-A, conducted outside during the summer, were relatively free of external symptoms of calcium and phosphorus deficiencies. Femoral fractures occurred in only one instance, this occurring during the winter experiment to an individual receiving a ration containing 0.3 and 0.2 per cent of calcium and phosphorus, respectively. This pig was isolated, with no dietary

Table 13. Experiments 605 and 605-A. Average daily gain[a] (lbs.)

Ca-P content of ration (%)	Weight at kill (lbs.) 100 Expt. no. 605	605A	150 Expt. no. 605	605A	200 Expt. no. 605	605A
0.2-0.2	1.54	1.30	1.68	1.58	1.39	1.31
0.3-0.2	1.10	1.29	1.15	1.57	1.76	1.13
0.4-0.2	0.98	1.25	1.60	1.43	1.57	1.36
0.5-0.2	1.10	1.14	1.39	1.29	1.26	1.10
0.6-0.2	1.44	1.29	1.12	1.58	1.12	1.36
0.2-0.3	1.39	1.41	1.65	1.63	1.84	1.46
0.3-0.3	1.34	1.51	1.30	1.73	1.86	1.55
0.4-0.3	1.46	1.21	1.44	1.46	1.80	1.65
0.5-0.3	1.34	1.19	1.66	1.69	1.82	1.45
0.6-0.3	1.52	1.30	1.64	1.48	1.95	1.46
0.2-0.4	1.68	1.29	1.34	1.34	1.85	1.68
0.3-0.4	1.27	1.16	1.61	1.32	1.93	1.25
0.4-0.4	1.24	1.33	1.66	1.37	1.63	1.44
0.5-0.4	1.65	1.26	1.28	1.48	1.64	1.44
0.6-0.4	1.71	1.30	1.66	1.63[a]	1.67	1.29
0.7-0.4	1.78	1.24	1.65	1.61	1.72	1.32
0.8-0.4	1.57	1.41	1.61	1.68	1.70	1.46
0.5-0.5	1.16	1.41	1.72	1.64	1.39	1.14
0.6-0.5	1.46	1.25	1.88	1.55	1.49	1.76
0.7-0.5	1.46	1.27	1.66	1.60	1.72	1.44
0.8-0.5	1.48	1.44	1.47	1.66[a]	1.85	1.45
0.6-0.6	1.64	1.24	1.47	1.56	1.70	1.53
0.7-0.6	1.73	1.30	1.54	1.43	1.60	1.46
0.8-0.6	1.46	1.22	1.64[a]	1.47	1.69	1.71
0.7-0.7	1.65	1.26	1.75	1.60	2.06	1.47

[a]Estimated values

Table 14. Experiments 605 and 605-A. Weight of femurs at time of removal of soft tissue[a]
(grams)

Ca-P content of ration (%)	Weight at kill (lbs.) 100, Expt. no. 605	100, 605A	150, Expt. no. 605	150, 605A	200, Expt. no. 605	200, 605A
0.2-0.2	127.0	124.5	154.5	155.0	160.5	194.5
0.3-0.2	126.0	113.0	189.0	175.0	177.0	253.5
0.4-0.2	102.5	127.5	144.5	145.5	163.0	231.5
0.5-0.2	127.0	118.5	174.0	157.0	218.0	199.0
0.6-0.2	111.0	124.0	172.5	179.5	206.0	198.5
0.2-0.3	115.5	129.0	157.0	161.0	192.5	194.0
0.3-0.3	116.0	128.0	173.0	195.5	223.5	236.5
0.4-0.3	127.0	127.5	182.5	196.5	196.0	209.0
0.5-0.3	123.0	130.0	159.5	161.5	190.5	218.5
0.6-0.3	136.0	129.0	136.0	158.5	238.5	218.5
0.2-0.4	145.0	113.0	157.5	158.0	213.5	176.0
0.3-0.4	110.5	127.5	153.0	190.5	198.0	227.0
0.4-0.4	130.5	145.0	188.0	187.5	241.0	235.5
0.5-0.4	118.5	121.0	158.5	165.0	234.0	219.0
0.6-0.4	131.5	133.5	176.5	181.3[b]	204.0	230.5
0.7-0.4	126.5	118.5	158.5	177.0	198.5	202.5
0.8-0.4	117.0	133.5	167.5	187.5	272.0	181.0
0.5-0.5	131.0	138.0	201.0	171.5	181.0	211.0
0.6-0.5	131.0	138.5	181.5	164.5	256.0	200.5
0.7-0.5	125.5	148.5	173.0	163.0	230.0	258.5
0.8-0.5	124.5	152.5	164.5	186.7[b]	221.5	238.0
0.6-0.6	129.5	152.0	168.0	168.0	256.5	205.5
0.7-0.6	135.5	136.0	184.5	169.0	218.5	217.0
0.8-0.6	134.0	134.5	183.8[b]	178.5	192.0	220.0
0.7-0.7	110.0	126.5	166.5	190.5	201.5	218.5

[a]Each value is an average of two femurs
[b]Estimated values

Table 15. Experiments 605 and 605-A. Breaking strength of femurs[a] (lbs. per sq. in.)

Ca-P content of ration (%)	Weight at kill (lbs.) 100 Expt. no. 605	605A	150 Expt. no. 605	605A	200 Expt. no. 605	605A
0.2-0.2	410	362	382	461	667	1174
0.3-0.2	187	390	863	936	769	1278
0.4-0.2	236	560	600	634	750	1570
0.5-0.2	232	322	617	1007	1086	1329
0.6-0.2	412	420	394	1083	916	1214
0.2-0.3	440	441	596	828	1034	859
0.3-0.3	398	556	864	982	1286	1066
0.4-0.3	398	474	808	820	930	996
0.5-0.3	639	638	870	972	1105	1417
0.6-0.3	435	566	775	1002	1138	1375
0.2-0.4	593	454	620	740	1141	775
0.3-0.4	541	425	690	976	1107	922
0.4-0.4	636	454	816	918	1192	1618
0.5-0.4	757	439	516	872	1394	1328
0.6-0.4	702	653	1072	581[b]	1288	1295
0.7-0.4	654	628	993	1095	987	918
0.8-0.4	646	736	1088	1045	1122	1214
0.5-0.5	751	566	969	973	1054	1022
0.6-0.5	696	772	1049	861	1350	1260
0.7-0.5	722	646	1052	840	1312	1512
0.8-0.5	780	734	1118	765[b]	1348	1558
0.6-0.6	684	862	976	1126	1234	1089
0.7-0.6	689	790	981	880	1305	1354
0.8-0.6	648	666	1031[b]	976	1325	1586
0.7-0.7	676	554	972	1168	1306	1392

[a]Each value is an average of two femurs
[b]Estimated value

Table 16. Experiments 605 and 605-A. Water content of ground femurs[a] (per cent)

Ca-P content of ration (%)	Weight at kill (lbs.) 100 Expt. no. 605	605A	150 Expt. no. 605	605A	200 Expt. no. 605	605A
0.2-0.2	52.8	52.0	44.3	42.8	28.1	33.2
0.3-0.2	51.4	50.0	34.3	39.2	36.4	32.5
0.4-0.2	51.2	52.4	41.8	41.6	41.6	31.4
0.5-0.2	52.8	46.1	42.9	35.8	29.4	30.0
0.6-0.2	51.0	41.3	42.6	36.7	30.9	30.7
0.2-0.3	52.8	50.0	44.5	42.6	34.1	39.6
0.3-0.3	50.3	47.0	37.5	41.2	38.5	33.3
0.4-0.3	54.6	46.6	40.0	40.0	33.4	32.6
0.5-0.3	50.2	44.8	40.7	34.6	35.8	31.9
0.6-0.3	49.6	45.6	40.4	37.9	37.0	28.9
0.2-0.4	51.7	46.5	43.2	38.4	31.4	29.0
0.3-0.4	49.0	41.4	46.6	38.0	35.3	31.6
0.4-0.4	49.8	43.2	37.4	38.0	30.8	29.4
0.5-0.4	45.3	46.9	37.1	35.8	34.2	34.0
0.6-0.4	47.0	45.6	38.2	39.3[b]	35.2	30.1
0.7-0.4	44.6	42.4	37.9	39.2	36.6	34.0
0.8-0.4	43.7	41.3	39.1	37.6	35.2	31.4
0.5-0.5	42.4	44.4	39.9	37.6	33.2	31.8
0.6-0.5	49.0	41.4	40.6	40.8	32.0	34.8
0.7-0.5	45.7	48.8	37.0	37.8	33.8	32.9
0.8-0.5	43.8	43.4	36.5	35.3[b]	34.6	33.0
0.6-0.6	43.1	43.4	37.3	38.2	34.5	30.6
0.7-0.6	47.6	45.0	37.2	31.6	29.1	32.5
0.8-0.6	49.4	42.6	37.3[b]	38.6	32.6	31.2
0.7-0.7	47.0	44.6	35.2	34.8	34.8	31.5

[a]Each value is an average of two femurs
[b]Estimated value

Table 17. Experiments 605 and 605-A. Fat content of water-free bones[a] (per cent)

Ca-P content of ration (%)	Weight at kill (lbs.) 100, Expt. no. 605	100, 605A	150, Expt. no. 605	150, 605A	200, Expt. no. 605	200, 605A
0.2-0.2	30.1	26.4	36.7	33.6	37.8	24.0
0.3-0.2	33.2	23.2	36.1	32.4	33.0	28.2
0.4-0.2	32.6	22.7	34.5	29.2	31.2	21.0
0.5-0.2	29.4	27.4	32.8	28.4	39.1	30.0
0.6-0.2	31.2	26.4	35.6	32.0	38.8	31.0
0.2-0.3	27.2	22.8	31.0	27.6	37.4	30.6
0.3-0.3	28.2	24.8	33.8	27.5	27.8	35.7
0.4-0.3	24.4	26.6	34.9	27.4	35.2	32.0
0.5-0.3	24.6	26.0	31.1	30.8	27.6	31.2
0.6-0.3	27.4	22.6	30.6	23.7	30.2	26.4
0.2-0.4	27.9	27.2	32.4	31.2	33.7	26.0
0.3-0.4	26.6	31.3	31.2	28.7	33.6	29.6
0.4-0.4	25.3	27.4	36.6	28.1	36.0	24.8
0.5-0.4	23.8	20.9	35.3	23.4	27.5	23.9
0.6-0.4	25.0	20.5	28.4	26.5[b]	27.8	26.6
0.7-0.4	26.0	20.2	28.1	19.1	27.4	27.4
0.8-0.4	24.6	24.0	24.2	23.7	30.6	30.9
0.5-0.5	23.8	24.0	33.4	24.2	30.0	28.0
0.6-0.5	22.0	26.4	25.8	22.4	26.8	28.2
0.7-0.5	22.0	20.8	30.0	22.4	29.4	27.2
0.8-0.5	24.6	18.6	23.6	23.5[b]	27.5	20.4
0.6-0.6	27.6	21.8	28.7	22.3	29.6	28.6
0.7-0.6	20.0	21.0	27.6	27.7	32.8	25.4
0.8-0.6	21.2	21.8	22.8[b]	24.1	28.6	25.6
0.7-0.7	21.2	22.2	28.8	23.4	28.4	23.4

[a]Each value is an average of two femurs
[b]Estimated value

Table 18. Experiments 605 and 605-A. Ash content of water-free, fat-free bones[a]

(per cent)

Ca-P content of ration (%)	Weight at kill (lbs.) 100 Expt. no. 605	605A	150 Expt. no. 605	605A	200 Expt. no. 605	605A
0.2-0.2	51.8	43.8	50.4	42.0	56.0	56.8
0.3-0.2	51.0	47.6	55.1	51.1	52.0	56.4
0.4-0.2	44.0	44.2	52.2	49.0	56.3	57.7
0.5-0.2	45.5	48.2	51.6	53.3	58.2	57.2
0.6-0.2	47.2	54.1	49.8	51.9	57.6	54.4
0.2-0.3	47.8	46.8	51.7	50.2	56.8	52.0
0.3-0.3	48.4	48.8	55.9	53.2	59.0	53.6
0.4-0.3	48.6	47.2	53.6	52.4	57.8	55.0
0.5-0.3	51.6	50.0	55.7	51.8	57.9	55.4
0.6-0.3	48.6	50.6	55.6	54.0	57.8	57.8
0.2-0.4	50.2	50.3	52.5	51.6	59.6	56.2
0.3-0.4	50.1	48.6	53.6	51.4	57.5	56.2
0.4-0.4	51.8	51.6	54.4	53.2	59.4	58.6
0.5-0.4	56.0	50.3	54.6	57.0	61.0	57.3
0.6-0.4	54.6	50.5	58.2	53.8[b]	59.5	57.3
0.7-0.4	55.6	50.2	59.3	55.0	59.1	54.4
0.8-0.4	57.3	52.9	58.8	54.2	59.6	56.3
0.5-0.5	56.5	51.0	55.7	54.6	60.4	56.4
0.6-0.5	54.2	52.0	56.0	57.6	61.8	60.1
0.7-0.5	55.6	48.4	59.1	55.2	59.9	57.5
0.8-0.5	56.9	52.1	60.8	57.9[b]	59.0	52.0
0.6-0.6	56.4	53.0	59.0	55.4	60.0	57.2
0.7-0.6	56.0	51.5	58.8	57.3	62.0	57.4
0.8-0.6	54.4	52.3	58.9[b]	54.5	59.6	52.0
0.7-0.7	55.4	50.8	60.4	54.3	58.8	57.8

[a]Each value is an average of two femurs
[b]Estimated values

Table 19. Experiments 605 and 605-A. Phosphorus content of femur ash[a] (per cent)

Ca-P content of ration (%)	Weight at kill (lbs.) 100 Expt. no. 605	605A	150 Expt. no. 605	605A	200 Expt. no. 605	605A
0.2-0.2	17.9	16.6	17.9	19.0	18.4	18.6
0.3-0.2	17.6	18.7	17.8	19.1	18.4	17.8
0.4-0.2	17.3	18.3	17.6	18.4	18.0	18.2
0.5-0.2	17.4	17.9	18.2	17.8	17.6	18.2
0.6-0.2	18.2	19.8	18.4	19.0	17.3	18.2
0.2-0.3	18.3	17.2	18.3	20.6	18.2	18.2
0.3-0.3	18.5	17.4	17.6	19.4	17.8	18.4
0.4-0.3	17.9	17.9	17.5	20.0	17.6	18.6
0.5-0.3	18.0	17.2	18.2	18.7	17.4	18.2
0.6-0.3	18.0	17.4	17.5	19.2	17.2	18.1
0.2-0.4	18.1	18.1	17.6	18.6	18.0	18.0
0.3-0.4	18.2	17.2	18.2	19.6	18.3	18.4
0.4-0.4	18.2	18.5	17.4	20.4	17.4	18.3
0.5-0.4	18.0	18.1	17.4	18.6	18.2	18.2
0.6-0.4	18.0	18.4	18.5	17.1[b]	18.6	18.0
0.7-0.4	17.9	18.0	17.7	19.2	18.2	18.2
0.8-0.4	18.0	18.2	17.6	19.6	18.8	18.1
0.5-0.5	18.2	18.5	17.6	17.7	17.8	18.4
0.6-0.5	18.4	17.6	18.0	17.8	18.3	18.2
0.7-0.5	17.6	18.1	17.5	18.2	17.9	17.8
0.8-0.5	18.3	17.4	18.3	18.5[b]	17.8	17.8
0.6-0.6	18.0	17.5	17.5	19.4	17.8	18.2
0.7-0.6	18.3	17.6	18.0	20.2	18.4	18.4
0.8-0.6	18.4	18.2	18.3[b]	18.6	18.5	18.3
0.7-0.7	18.1	18.3	17.8	20.7	17.8	18.3

[a]Each value is the average of two femurs
[b]Estimated value

Table 20. Experiments 605 and 605-A. Summary of feed required per pound of gain

(lbs.)

Ca-P content of ration (%)	Experiment 605	Experiment 605A
0.2-0.2	2.61	2.94
0.3-0.2	2.62	3.14
0.4-0.2	2.61	3.15
0.5-0.2	2.85	3.18
0.6-0.2	2.86	3.06
0.2-0.3	2.73	2.79
0.3-0.3	2.76	2.72
0.4-0.3	2.75	2.89
0.5-0.3	2.76	2.92
0.6-0.3	2.65	3.15
0.2-0.4	2.78	2.91
0.3-0.4	2.64	3.27
0.4-0.4	2.55	2.92
0.5-0.4	2.94	3.04
0.6-0.4	2.79	2.97[a]
0.7-0.4	2.82	2.92
0.8-0.4	2.79	3.00
0.5-0.5	2.82	3.42
0.6-0.5	2.76	3.01
0.7-0.5	2.77	3.13
0.8-0.5	2.79	3.04[a]
0.6-0.6	2.67	3.14
0.7-0.6	2.85	3.10
0.8-0.6	3.06[a]	2.96
0.7-0.7	2.76	3.22

[a]Estimated values

change, and complete healing of both femoral fractures occurred. The radiographs of the isolated femurs from this pig are shown in Figures 6 and 7.

Radiographs were taken when an individual expressed outward symptoms of possible skeletal abnormalities. While there was only one instance of femoral fracture discovered there were noticeable changes in many of the femurs. Typical of these are the femurs shown in Figure 8. These femurs were taken from an animal which received 0.6 and 0.3 per cent calcium and phosphorus, respectively. The radiograph indicates that femurs were compacted, the femur necks were thickened and the left foreshortened, as compared with the right. These femurs are not fractured.

The flame spectrophotometric determinations of calcium, sodium, magnesium and potassium were conducted only upon femur ash from pigs in experiments 605 and 605-A. These data are presented in Tables 21 through 24. Since similar data were not available from the studies of Roberts (1953), an analysis of variance was conducted upon the results of the flame spectrophotometric analysis, according to the plan in Table 30 of the appendix. There was no significant difference in calcium, sodium or magnesium content demonstrated in any of the femur ash. Potassium became significantly lower as the pigs became heavier. There was no other significant effect upon potassium content of the ash.

Individual statistical analysis was not conducted of the data for the other evaluating criteria of experiments 605 and 605-A. An examination of the data in Tables 14 through 18 shows that variation in

Figure 6. Radiograph of left femur of pig which received 0.3 and 0.2 per cent of calcium and phosphorus

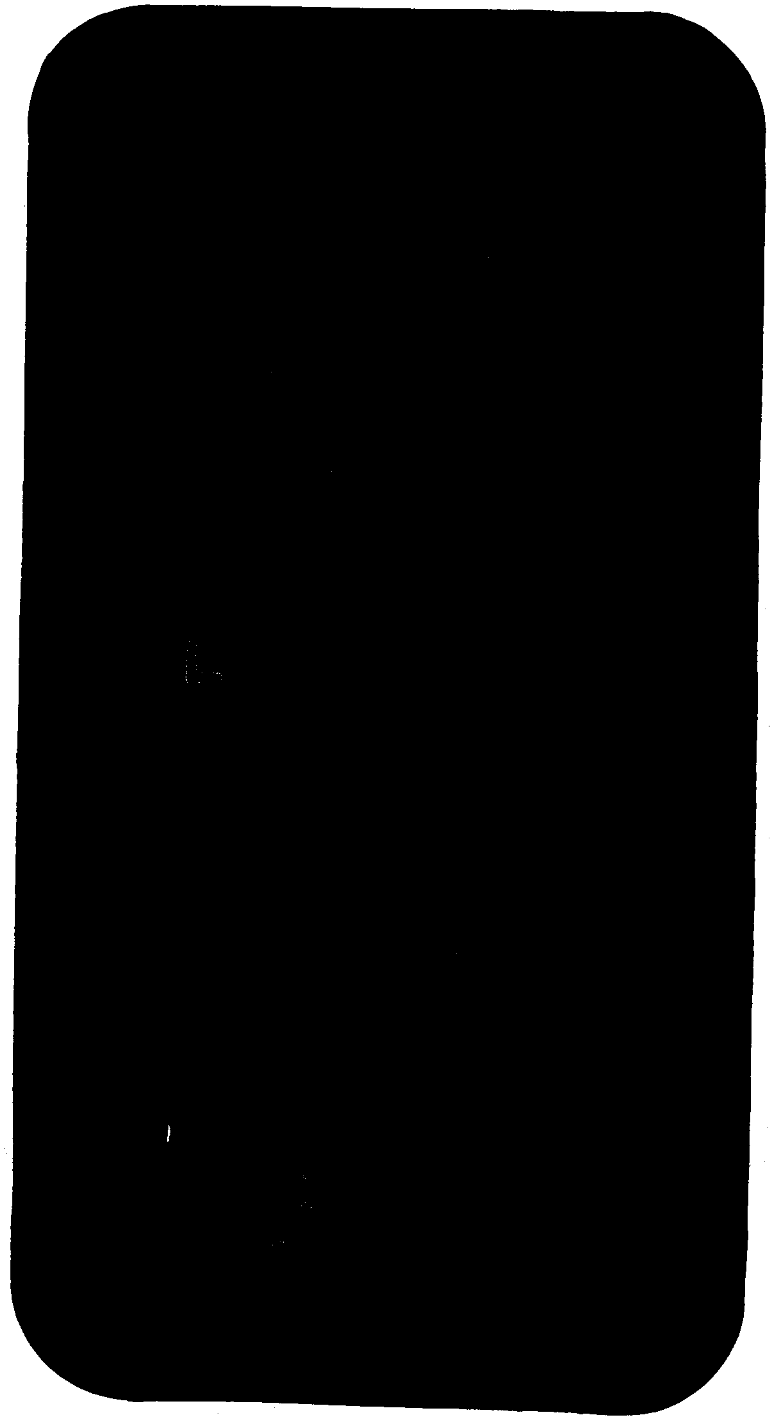

Figure 7. Radiograph of right femur from pig which received 0.3 and 0.2 per cent of calcium and phosphorus

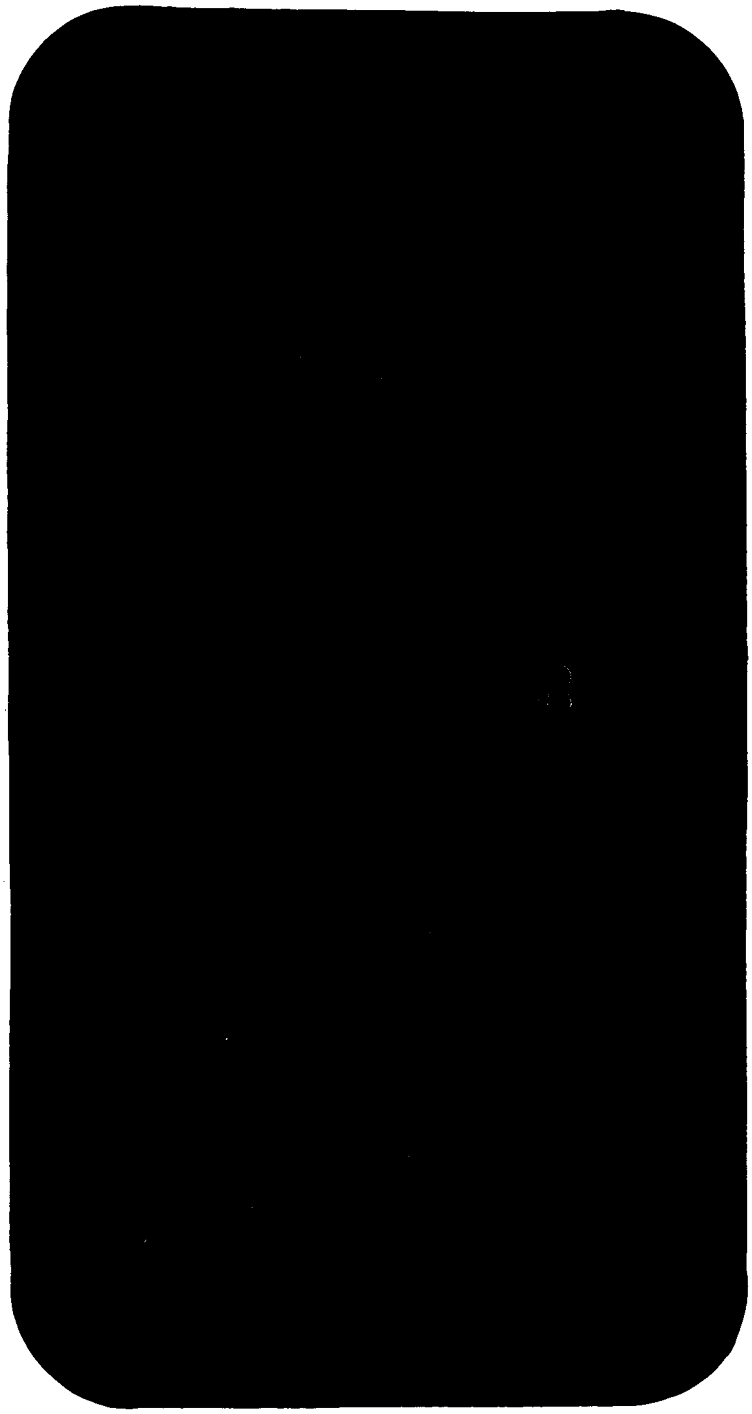

Figure 8. Femurs from pig which received 0.6 and 0.3 per cent of calcium and phosphorus

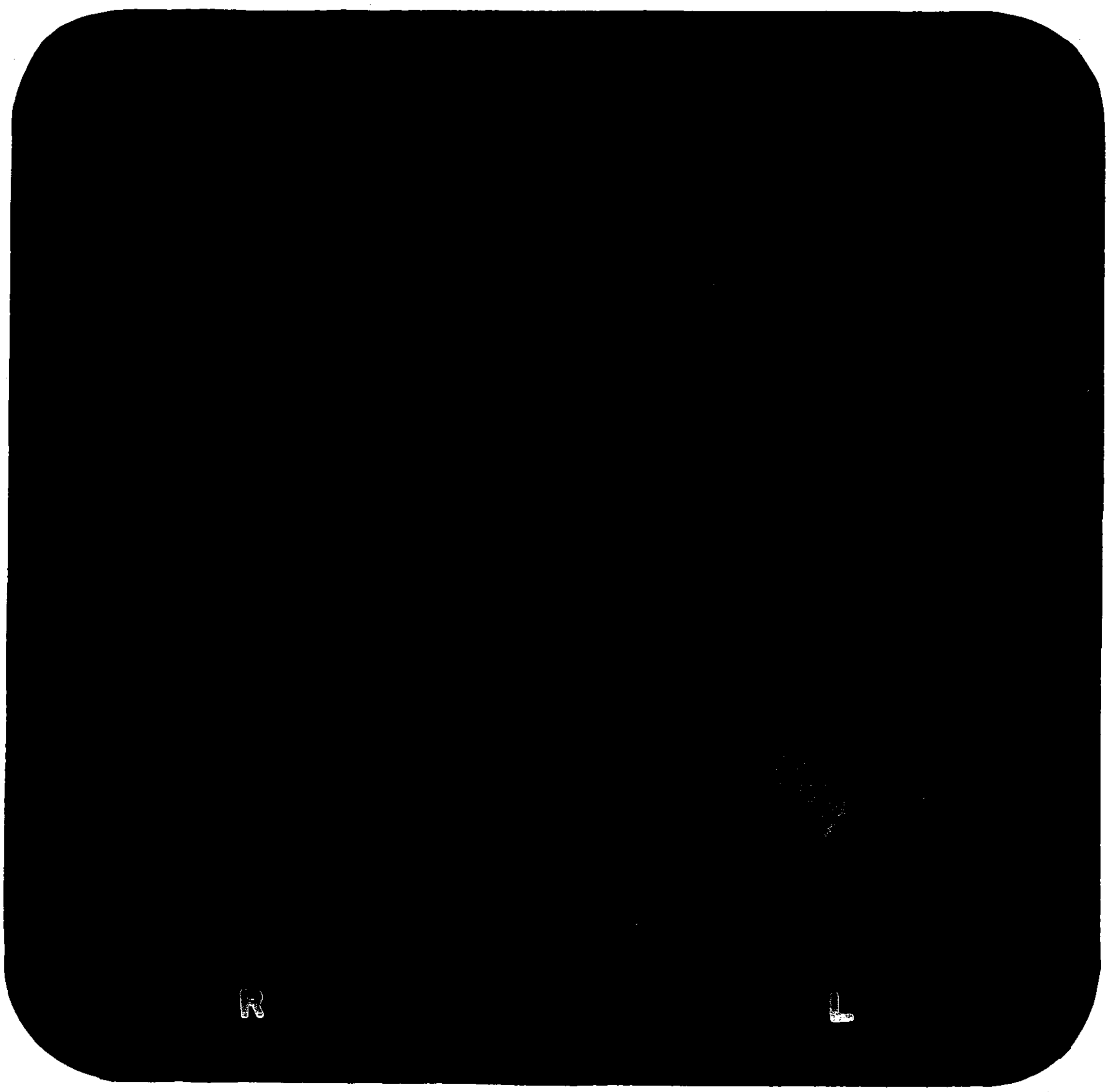
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Table 21. Calcium content of femur ash[a] (per cent)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	34.3	34.2	35.1	36.0	34.8		
	150	35.7	36.9	35.7	33.9	37.9		
	200	35.1	36.2	34.3	35.0	37.7		
0.3	100	33.8	33.3	32.8	33.2	34.0		
	150	34.4	34.6	34.6	34.4	33.8		
	200	34.4	37.2	35.6	37.6	35.1		
0.4	100	33.1	33.2	33.7	33.0	33.1	34.7	33.1
	150	33.4	35.7	34.3	35.4	35.6	36.2	36.0
	200	37.2	35.3	36.0	36.0	35.6	36.4	35.0
0.5	100				35.2	33.0	33.4	35.0
	150				34.4	34.6	36.5	33.6
	200				35.2	37.2	36.8	36.0
0.6	100					33.0	33.6	33.0
	150					34.3	36.8	36.3
	200					35.4	35.0	35.8
0.7	100						35.4	
	150						37.4	
	200						36.0	

[a]Average of experiments 605 and 605A

Table 22. Potassium content of femur ash[a] (p.p.m.)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	4.8	5.2	5.2	5.5	5.4		
	150	3.6	2.8	3.0	4.2	4.0		
	200	2.2	3.2	3.3	3.0	2.0		
0.3	100	4.6	5.6	4.6	5.0	4.0		
	150	4.4	4.0	3.9	3.7	4.0		
	200	3.2	2.0	2.7	2.4	2.4		
0.4	100	5.2	4.0	3.8	3.4	3.8	3.8	4.9
	150	3.4	4.1	3.4	3.8	3.0	2.7	3.2
	200	2.4	2.8	2.2	2.2	2.2	2.0	3.2
0.5	100				3.1	4.2	3.5	4.4
	150				3.4	3.4	2.4	3.4
	200				2.2	1.8	2.8	2.6
0.6	100					4.1	4.0	5.0
	150					3.0	2.6	3.2
	200					2.7	2.5	2.8
0.7	100						3.6	
	150						2.8	
	200						2.0	

[a]Average of experiments 605 and 605-A

Table 23. Magnesium content of femur ash[a] (p.p.m.)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%) 0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	18.8	17.6	17.4	18.8	18.8		
	150	18.0	18.6	18.8	18.2	19.4		
	200	17.2	17.8	18.5	17.2	14.4		
0.3	100	19.1	18.2	18.8	18.2	18.8		
	150	18.3	18.2	18.2	18.0	18.6		
	200	17.2	18.9	18.0	18.6	18.0		
0.4	100	18.8	18.8	18.8	18.8	19.4	18.2	17.6
	150	18.6	18.0	18.6	18.6	17.2	18.2	18.0
	200	18.6	17.2	17.5	17.8	16.6	17.2	17.5
0.5	100				18.8	17.4	17.6	19.4
	150				19.1	18.3	19.1	18.8
	200				17.8	16.6	17.1	17.8
0.6	100					17.6	18.2	17.6
	150					18.8	17.1	17.4
	200					18.0	17.2	17.0
0.7	100						18.8	
	150						17.5	
	200						17.8	

[a]Average of experiments 605 and 605-A

Table 24. Sodium content of femur ash[a]
(p.p.m.)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration 0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	20.2	18.6	20.4	20.4	21.2		
	150	18.4	17.2	18.0	17.4	15.6		
	200	18.4	19.6	20.0	18.6	15.4		
0.3	100	19.2	19.8	19.2	20.2	19.1		
	150	18.5	18.0	19.3	17.8	17.4		
	200	17.4	17.8	18.5	16.0	18.6		
0.4	100	20.8	19.1	18.4	17.2	18.2	17.2	18.5
	150	16.4	19.2	15.9	18.0	19.2	19.6	17.4
	200	17.8	18.2	17.6	17.8	17.8	17.2	19.2
0.5	100				19.1	17.0	18.0	18.8
	150				17.2	18.5	17.2	16.6
	200				17.4	18.2	16.3	16.3
0.6	100					17.0	16.8	20.4
	150					16.0	18.5	17.6
	200					16.9	17.6	18.2
0.7	100						19.8	
	150						17.4	
	200						18.0	

[a]Average of experiments 605 and 605-A

these measures, associated with variation in the phosphorus and calcium content of the diet, was essentially the same as when these data were pooled with that of Roberts (1953). Therefore, to eliminate repitition, discussion of these will be postponed until the pooled data are presented.

The animals in each lot were group fed, making an accurate measure of the feed consumption of each individual animal impossible. Feed efficiency (Table 20) was therefore computed using the lot as the experimental unit. There were no apparent consistent trends in variations of feed efficiency which could be associated with changes in the dietary levels of calcium and phosphorus. The majority of the groups exhibited satisfactory efficiency of feed utilization.

Seasonal differences

As shown by the analysis of variance in Table 28, significant differences occurred in average daily gain only from weaning to 100 pounds of body weight. An examination of the data (Table 25) reveals this difference to be inconsistent, with an apparent tendency to disappear as the dietary levels of calcium and phosphorus increase. There was no consistent trend in rate of gain within seasons within the two larger weight groups.

However, the data in Table 26 and Table 27 show differences in breaking strength and ash content of bone between season that were statistically significant in all but one instance (Table 28). Breaking strength of the femurs was significantly higher during the summer for the 150 and 200 pound pigs. There was no significant difference

Table 25. Summary of average daily gains by seasons[a]
(pounds)

Ca-P content of ration (%)	Weight at kill (lbs.) 100		150		200	
	Season		Season		Season	
	Summer[a]	Winter[b]	Summer[a]	Winter[b]	Summer[a]	Winter[b]
0.2-0.2	1.34	1.44	1.57	1.34	1.42	1.43
0.3-0.2	1.22	1.06	1.52	1.12	1.43	1.34
0.4-0.2	1.36	0.91	1.22	1.32	1.38	1.46
0.5-0.2	1.16	1.10	1.38	1.48	1.15	1.31
0.6-0.2	1.24	1.13	1.46	1.22	1.40	1.14
0.2-0.3	1.41	1.31	1.50	1.70	1.62	1.90
0.3-0.3	1.48	1.23	1.79	1.30	1.67	1.68
0.4-0.3	1.42	1.28	1.52	1.36	1.69	1.62
0.5-0.3	1.34	1.01	1.68	1.34	1.53	1.48
0.6-0.3	1.44	1.38	1.50	1.58	1.56	1.56
0.2-0.4	1.39	1.43	1.32	1.38	1.58	1.76
0.3-0.4	1.28	1.47	1.24	1.72	1.40	1.90
0.4-0.4	1.60	1.26	1.48	1.66	1.47	1.64
0.5-0.4	1.52	1.44	1.60	1.66	1.56	1.70
0.6-0.4	1.44	1.63	1.54	1.74	1.56	1.64
0.7-0.4	1.54	1.60	1.66	1.49	1.58	1.70
0.8-0.4	1.47	1.30	1.67	1.56	1.63	1.71
0.5-0.5	1.62	1.35	1.55	1.85	1.42	1.56
0.6-0.5	1.54	1.38	1.62	1.82	1.70	1.34
0.7-0.5	1.48	1.46	1.61	1.80	1.55	1.75
0.8-0.5	1.52	1.51	1.65	1.68	1.76	1.58
0.6-0.6	1.51	1.67	1.54	1.44	1.59	1.52
0.7-0.6	1.62	1.52	1.55	1.58	1.65	1.52
0.8-0.6	1.58	1.42	1.59	1.68	1.64	1.72
0.7-0.7	1.42	1.58	1.54	1.84	1.66	1.78

[a]Each value is an average of experiments 605-A and 557-1
[b]Each value is an average of experiments 605 and 557-2

Table 26. Summary of ash content of femurs by seasons (per cent)

Ca-P content of ration (%)	Weight at kill (lbs.) 100		150		200	
	Season		Season		Season	
	Summer[a]	Winter[b]	Summer[a]	Winter[b]	Summer[a]	Winter[b]
0.2-0.2	44.2	48.0	44.2	47.0	51.9	54.4
0.3-0.2	44.3	47.0	49.8	51.6	53.5	53.0
0.4-0.2	43.8	42.2	48.8	50.8	53.8	55.2
0.5-0.2	47.8	43.8	53.2	51.5	57.6	55.6
0.6-0.2	54.0	45.2	55.3	50.3	56.8	56.5
0.2-0.3	47.4	48.1	51.6	52.2	54.4	54.4
0.3-0.3	46.0	46.5	51.8	54.3	52.9	57.0
0.4-0.3	45.5	46.5	51.3	51.0	55.3	56.0
0.5-0.3	47.6	46.0	52.0	51.3	54.8	56.0
0.6-0.3	47.8	47.6	51.9	53.4	56.6	57.5
0.2-0.4	50.6	48.2	51.6	52.0	55.9	55.6
0.3-0.4	51.0	47.4	54.2	53.7	56.0	58.4
0.4-0.4	49.6	51.4	53.2	54.4	57.5	60.2
0.5-0.4	47.5	53.2	55.1	54.0	56.4	60.2
0.6-0.4	50.2	52.4	53.8	55.2	56.2	60.5
0.7-0.4	49.5	49.3	54.8	57.5	55.7	59.0
0.8-0.4	50.4	51.6	53.8	58.8	56.6	58.4
0.5-0.5	47.4	55.2	54.6	56.2	56.4	60.8
0.6-0.5	49.8	55.6	55.4	57.6	58.4	61.8
0.7-0.5	48.1	55.7	55.6	57.4	57.7	60.2
0.8-0.5	50.7	55.9	57.4	59.8	53.3	60.6
0.6-0.6	50.2	56.1	55.6	58.0	57.8	60.8
0.7-0.6	49.4	56.2	56.6	58.6	57.0	62.6
0.8-0.6	49.2	56.0	54.7	59.6	54.9	60.4
0.7-0.7	49.4	55.9	54.0	58.0	58.0	59.4

[a]Each value is an average of experiments 605-A and 557-1
[b]Each value is an average of experiments 605 and 557-2

Table 27. Summary of breaking strength of femurs by seasons (lbs. per sq. in.)

Ca-P content of ration (%)	Weight at kill (lbs.) 100 Season Summer[a]	Winter[b]	150 Season Summer[a]	Winter[b]	200 Season Summer[a]	Winter[b]
0.2-0.2	430	371	550	317	1125	727
0.3-0.2	306	168	794	666	996	716
0.4-0.2	431	140	609	558	1074	810
0.5-0.2	320	321	800	774	1178	1208
0.6-0.2	288	350	1042	601	1123	1053
0.2-0.3	481	522	772	788	816	983
0.3-0.3	533	297	885	814	985	1098
0.4-0.3	529	297	890	712	1070	778
0.5-0.3	614	338	953	773	1330	970
0.6-0.3	569	438	913	726	1254	1104
0.2-0.4	474	476	741	750	812	1160
0.3-0.4	562	516	937	826	925	1086
0.4-0.4	516	588	954	918	1326	1280
0.5-0.4	500	692	848	719	1322	1220
0.6-0.4	690	536	862	924	1235	1182
0.7-0.4	637	671	984	804	1123	1035
0.8-0.4	688	594	1071	1042	1256	1182
0.5-0.5	557	726	1046	1044	1169	1105
0.6-0.5	690	766	941	1084	1325	1265
0.7-0.5	683	693	1038	1086	1476	1296
0.8-0.5	758	845	1046	1100	1332	1363
0.6-0.6	775	720	1009	968	1335	1330
0.7-0.6	736	775	969	988	1323	1262
0.8-0.6	551	884	1125	1032	1592	1306
0.7-0.7	584	707	1092	954	1336	1102

[a]Each value is an average of experiments 605-A and 557-1
[b]Each value is an average of experiments 605 and 557-2

in breaking strength of femurs from the 100 pound pigs attributable to season. Ash content, on the other hand, was significantly higher for all weight groups during the winter.

<u>Pooled average results of experiments 605, 605-A, 557-1 and 557-2</u>

The validity of pooling data from these four experiments was discussed earlier. The data pooled included average daily gain, femur weight at time of removal of soft tissue, breaking strength of femurs, water content of ground femurs, fat content of water-free femurs, ash content of water-free, fat-free femurs, phosphorus content of bone ash and feed required per pound of gain. The summaries of these pooled data are presented in Tables 31 through 38 of the appendix.

The pooled data for average daily gain, breaking strength of femurs and ash content when analyzed statistically according to the plan in Table 28 revealed no interaction between ration treatment and season effect upon the results obtained. In lieu of this, these data from the four experiments could be considered as replications in the subsequent multiple regression analysis, conducted to determine the relation of these three criteria to the dietary levels of calcium and phosphorus.

A total of nine equations were computed, one for each of the three response criteria, for each of the three weight groups. The constants obtained in fitting the regression equation to the nine sets of data are shown in Tables 39 through 42. The regression equation was in turn used to compute predicted values for the three criteria of response at each of the three weight groups. These predicted values are given in Tables 43, 44 and 45.

The multiple correlation coefficients (R) are shown in Table 39. Each of the correlation coefficients were significant at the P = .01 level, all exceeding 0.8 and four exceeding 0.9. This indicates an excellent relationship between the dependent and independent variables.

The values of t for tests of significance of the partial regression coefficients are presented in Table 47. With one exception, there were significant or highly significant values for phosphorus within each criterion and weight group studied, indicating phosphorus exerted an effect upon the variations in the evaluating criteria as they were associated with the dietary levels of calcium and phosphorus. The majority of significant values for calcium occurred within the heaviest weight group, implying that calcium had more effect upon the results obtained in the heavier weight groups as compared with the lighter weight group.

Femur weight can be considered a function of body weight, and was so demonstrated. However, there was also a highly significant variation as the weight of the femurs associated with ration treatment. In the absence of a multiple regression analysis, it was not possible to define which of the elements expressed the most influence upon this criterion. However, femur weight was positively effected as calcium was increased across levels of dietary phosphorus of 0.2 through 0.5 per cent. The same trend was apparent when phosphorus levels were increased across all calcium levels up through 0.6 per cent.

There was a significant decrease in water content of the femurs with age. A highly significant effect of ration treatment also occurred. The data (Table 34) indicated that when calcium was increased across dietary phosphorus levels of 0.2, 0.3, 0.4 and 0.5 per cent, it was accompanied by a lowering of the water content in the femurs. A similar response did not appear so pronounced as the level of phosphorus was increased at the different levels of calcium.

The fat content of the femurs decreased significantly with age and treatment. The data show in Table 35 that as the levels of phosphorus are increased in the diet on all levels of calcium, there was a resultant lower fat content of the femurs. When phosphorus was furnished at levels of 0.4, 0.5 and 0.6 per cent, the fat content appeared to decrease as the dietary calcium level increased.

There were no significant differences in phosphorus content of femur ash attributable to replication, weight group or ration treatment.

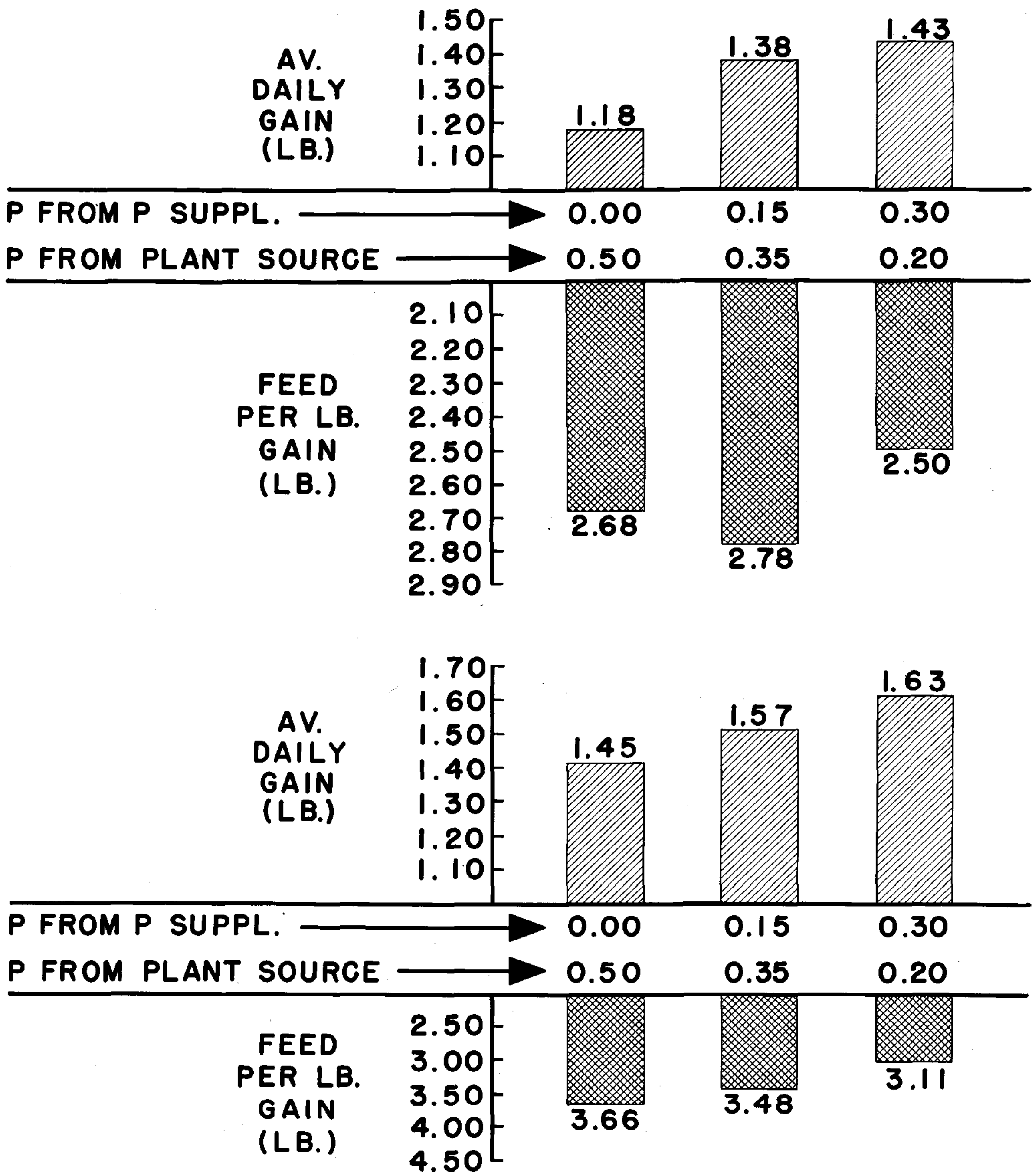
DISCUSSION

Experiment 593

The performance of the pigs receiving all-plant phosphorus rations was progressively improved as the content of phosphorus from plant sources was decreased and replaced by an equivalent amount of phosphorus from dicalcium phosphate. This is presented graphically in Figures 9 and 10. However, it is emphasized that such alteration in the proportionate amounts contributed from the two kinds of phosphorus had no significant effect on ash or phosphorus content of femurs or on breaking strength of the femurs. In earlier studies, Hart et al. (1909) reported that wheat bran could serve as the main source of dietary phosphorus for the skeletal development of growing swine, while Forbes (1914) compared phytin phosphorus to inorganic phosphorus and reported decreased rate of gain, feed efficiency and femur ash content when the phytin phosphorus was the only available source of phosphorus. The current data are in partial agreement with the latter in that there was a significantly decreased rate of gain and feed efficiency when the phosphorus was supplied entirely by plant sources. When the same levels of phosphorus from the different phosphorus supplements were fed, no significant correlation between blood serum inorganic phosphorus and experimental ration treatment could be demonstrated. This is in agreement with Bohstedt and coworkers (1926). However, there was a significant linear increase in the serum inorganic phosphorus levels when the proportion of inorganic phosphorus to plant

Figure 9. Experiment 593. Average daily gain and feed efficiency, 25 - 100 pounds

Figure 10. Experiment 593. Average daily gain and feed efficiency, 25 - 200 pounds



AV. DAILY GAIN (LB.)
1.50
1.40
1.30
1.20
1.10
1.18
1.38
1.43
P FROM P SUPPL.
0.00
0.15
0.30
P FROM PLANT SOURCE
0.50
0.35
0.20
FEED PER LB. GAIN (LB.)
2.10
2.20
2.30
2.40
2.50
2.60
2.70
2.80
2.90
2.68
2.78
2.50
AV. DAILY GAIN (LB.)
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.45
1.57
1.63
P FROM P SUPPL.
0.00
0.15
0.30
P FROM PLANT SOURCE
0.50
0.35
0.20
FEED PER LB. GAIN (LB.)
2.50
3.00
3.50
4.00
4.50
3.66
3.48
3.11

phosphorus increased. These results show that the pig cannot utilize phosphorus from plant sources as well as that from dicalcium phosphate.

Roberts (1953) suggested that for a margin of safety, phosphorus levels slightly in excess of those recommended by the National Research Council should be used in growing-finishing swine rations which contain chlortetracycline. It has been reported by Linblad et al. (1952) that chlortetracycline enhanced phosphorus utilization in poultry. This antibiotic did produce a lower mean average for breaking strength and per cent of phosphorus in femur ash. The differences were not statistically significant, however, and were not of sufficient magnitude to be considered conclusive. Chlortetracycline had no statistically significant effect upon bone ash or phosphorus content of blood serum of the growing-finishing pig. More definite differences would be needed before it could be concluded that the antibiotic had an effect upon phosphorus metabolism in the growing pig.

The responses of the pigs in this experiment were essentially the same when steamed bonemeal or dicalcium phosphate provided all of the phosphorus in the rations as measured by daily gain, daily feed intake and feed per 100 pound of gain. This is in agreement with observations made by Mitchell et al. (1937). The results of feeding the ghree different kinds of phosphate supplements to the pigs were in agreement with Gobble and Miller (1953) and Gobble et al. (1954) for phosphorus content of bone ash. However, contrary to the results of the tests reported herein, the latter workers reported no significant effect on the rate of gain, feed efficiency or femur bone ash content when colloidal phosphate was fed. The decreased rate of gain and feed efficiency (Figures 11 and 12) expressed by the pigs receiving colloidal clay as compared with those fed dicalcium phosphate or steamed bonemeal was statistically significant as was the decreased breaking strength and femur ash content shown in Figures 13 and 14. The type of phosphorus supplement exerted no significant effect on blood serum inorganic phosphorus.

There was no significant difference in phosphorus content of femurs from pigs fed the three phosphorus supplements. There also was a many fold increase in fluorine content of the femurs, accompanied by the apparent calcification of the matrix in the posterior portions of the medullary cavity at the femurs of swine receiving colloidal clay. This suggests that the decreased breaking strength and increased ash content may be the result of structural or physical changes in the crystals of hydroxyapatite or bone mineral. Mitchell and Edman (1952), in their review, state that the growing pig can tolerate 0.014 per cent fluorine from rock phosphate in the dry matter consumed. Figure 15 shows that the average fluorine in the ration, for the two levels of colloidal clay fed, were 0.025 and 0.045 per cent, respectively. These data are in contrast to Shrewsbury and Vestal (1945) who could not relate their results with the dietary level of fluorine. They are not necessarily in disagreement with Gobble and Miller (1953) and Gobble, Miller and Sherritt (1954), who stated they observed no gross symptoms of fluorosis. Such gross symptoms would not be expected to express themselves in a short term feeding trial. However, in view of the considerations

Figure 11. Experiment 593. Average daily gain and feed efficiency for pigs receiving steamed bonemeal, colloidal clay and dicalcium phosphate, 25 - 100 pounds

Figure 12. Experiment 593. Average daily gain and feed efficiency for pigs receiving steamed bonemeal, colloidal clay and dicalcium phosphate, 25 - 200 pounds

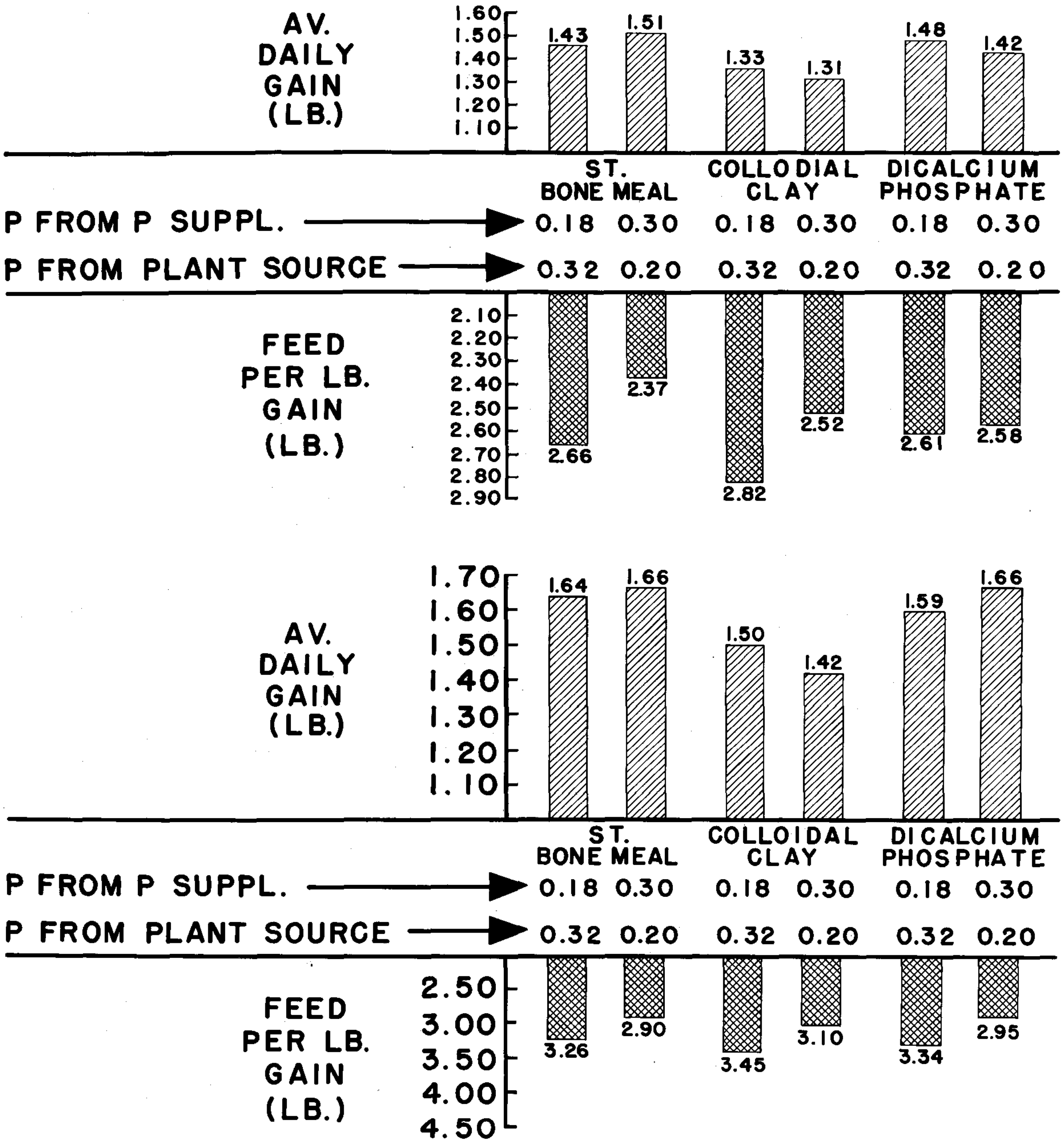
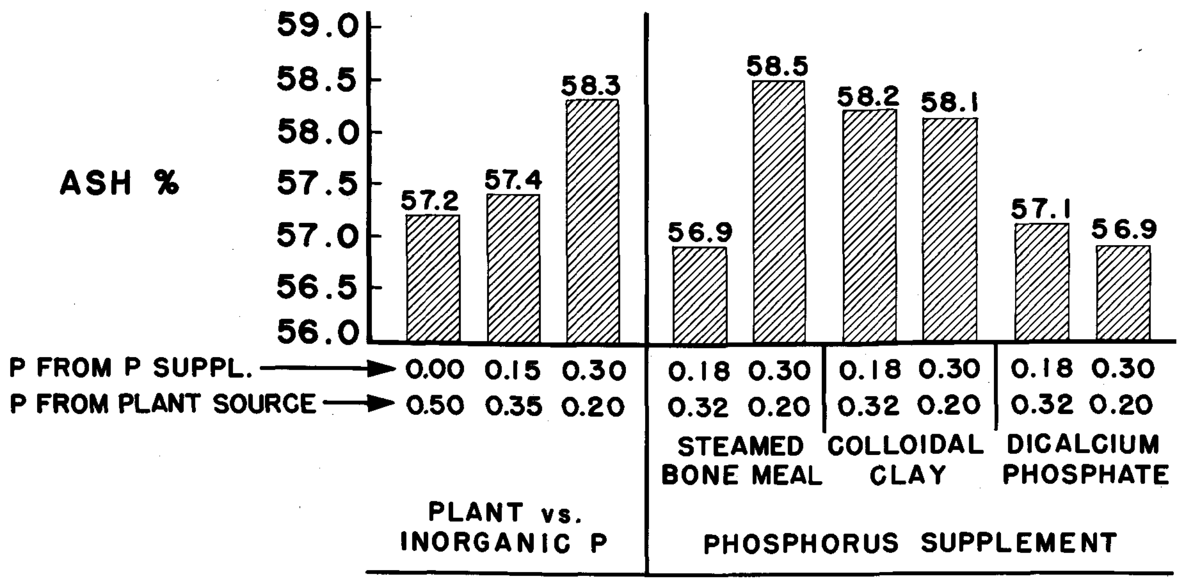

AV. DAILY GAIN (LB.)
1.60
1.50
1.40
1.30
1.20
1.10
1.43
1.51
1.33
1.31
1.48
1.42
ST. BONE MEAL
COLLODIAL CLAY
DICALCIUM PHOSPHATE
P FROM P SUPPL.
0.18 0.30 0.18 0.30 0.18 0.30
P FROM PLANT SOURCE
0.32 0.20 0.32 0.20 0.32 0.20
FEED PER LB. GAIN (LB.)
2.10
2.20
2.30
2.40
2.50
2.60
2.70
2.80
2.90
2.66
2.37
2.82
2.52
2.61
2.58
AV. DAILY GAIN (LB.)
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.64
1.66
1.50
1.42
1.59
1.66
ST. BONE MEAL
COLLOIDAL CLAY
DICALCIUM PHOSPHATE
P FROM P SUPPL.
0.18 0.30 0.18 0.30 0.18 0.30
P FROM PLANT SOURCE
0.32 0.20 0.32 0.20 0.32 0.20
FEED PER LB. GAIN (LB.)
2.50
3.00
3.50
4.00
4.50
3.26
2.90
3.45
3.10
3.34
2.95

Figure 13. Experiment 593. Ash content of water-free- fat-free femurs

Figure 14. Experiment 593. Breaking strength of femurs


ASH %
59.0
58.5
58.0
57.5
57.0
56.5
56.0
57.2
57.4
58.3
56.9
58.5
58.2
58.1
57.1
56.9
P FROM P SUPPL.
P FROM PLANT SOURCE
0.00 0.15 0.30
0.50 0.35 0.20
0.18 0.30
0.32 0.20
0.18 0.30
0.32 0.20
0.18 0.30
0.32 0.20
STEAMED BONE MEAL
COLLOIDAL CLAY
DICALCIUM PHOSPHATE
PLANT vs. INORGANIC P
PHOSPHORUS SUPPLEMENT

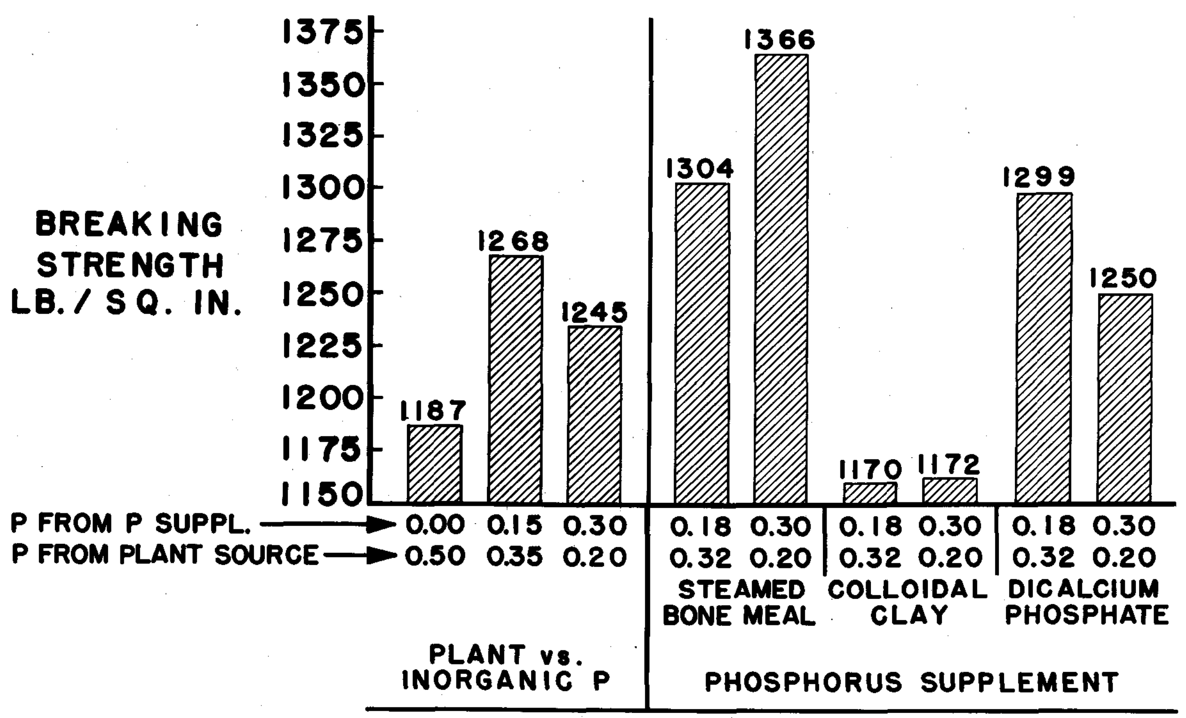
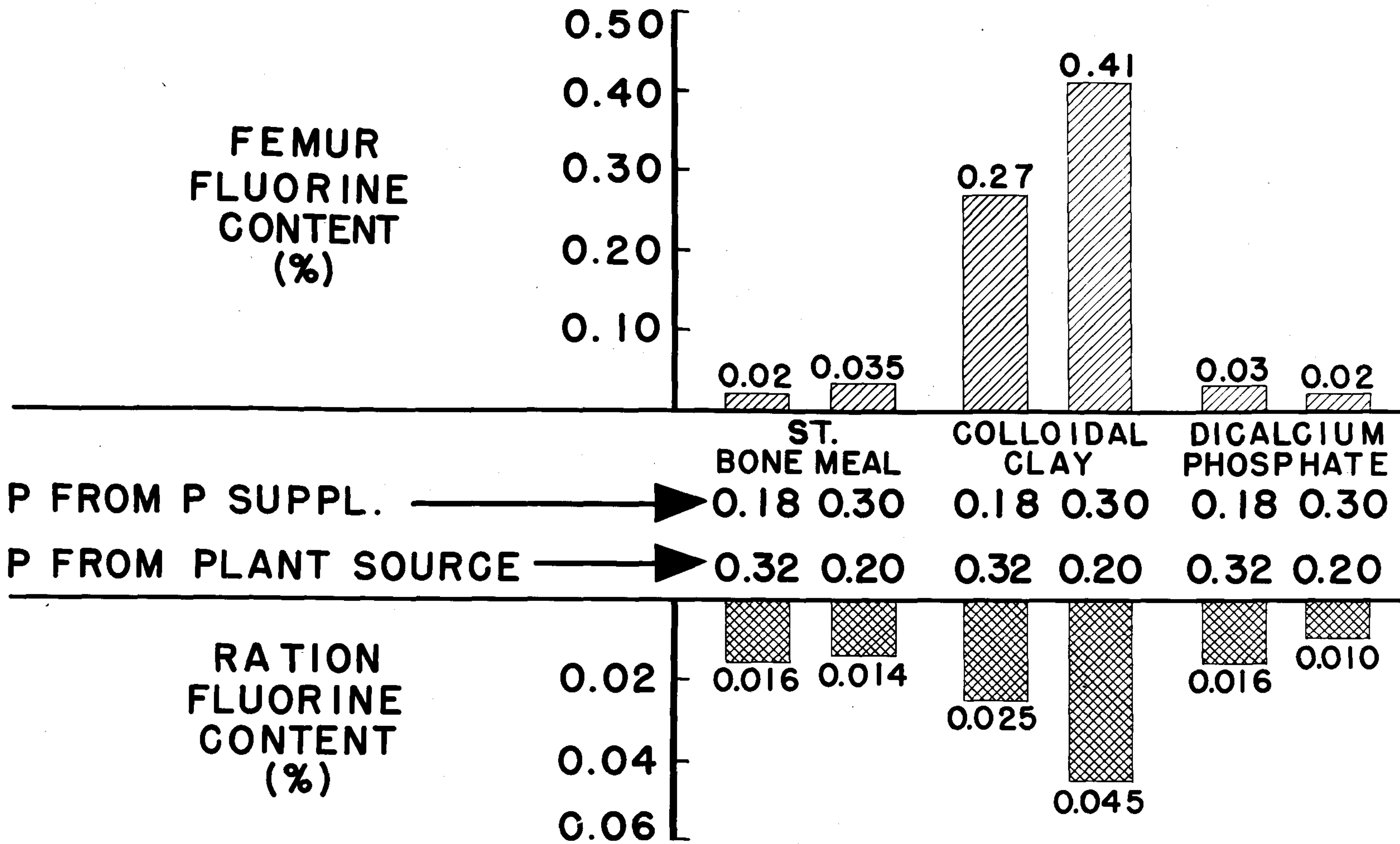

BREAKING STRENGTH LB./SQ. IN.
1375
1350
1325
1300
1275
1250
1225
1200
1175
1150
1187
1268
1245
1304
1366
1170
1172
1299
1250
P FROM P SUPPL.
P FROM PLANT SOURCE
0.00 0.15 0.30
0.50 0.35 0.20
0.18 0.30
0.32 0.20
0.18 0.30
0.32 0.20
0.18 0.30
0.32 0.20
STEAMED BONE MEAL
COLLOIDAL CLAY
DICALCIUM PHOSPHATE
PLANT vs. INORGANIC P
PHOSPHORUS SUPPLEMENT

Figure 15. Fluorine content of rations fed to, and femurs from, pigs receiving colloidal clay


FEMUR FLUORINE CONTENT (%)
0.50
0.40
0.30
0.20
0. 10
0.02
0.035
0.27
0.41
0.03
0.02
ST. BONE MEAL
COLLOIDAL CLAY
DICALCIUM PHOSPHATE
P FROM P SUPPL.
0.18 0.30 0.18 0.30 0.18 0.30
P FROM PLANT SOURCE
0.32 0.20 0.32 0.20 0.32 0.20
RATION FLUORINE CONTENT (%)
0.02
0.04
0.06
0.016
0.014
0.025
0.045
0.016
0.010

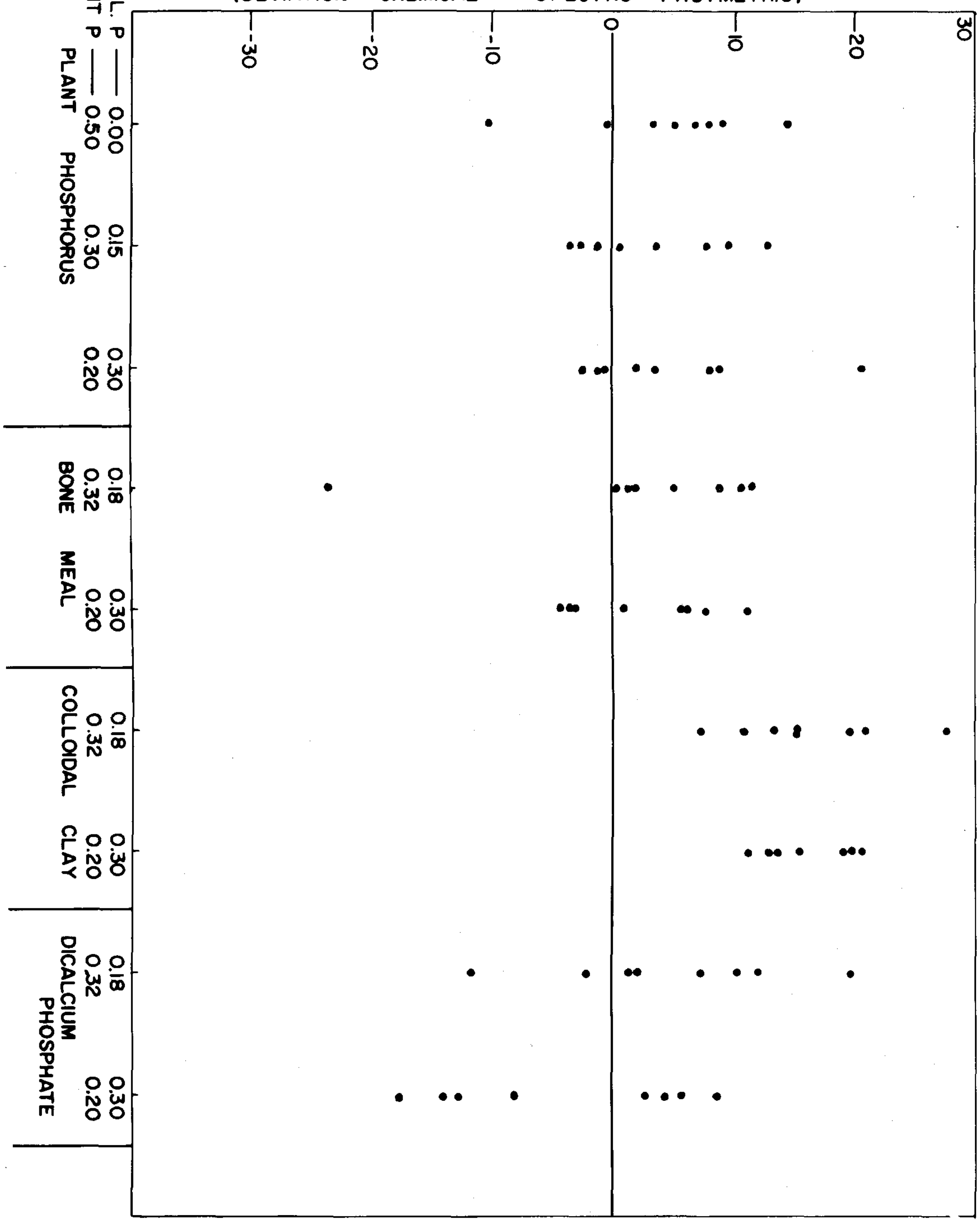
herein, a potential fluorine toxicological hazard is in the realm of possibility. One may suggest that if colloidal clay is to be used as a phosphate source for the pig, consideration be given to the question of what constitutes the maximum amount that may be safely added to rations for growing-finishing swine.

The results from analyzing the femur ash for calcium, potassium, sodium and magnesium are not entirely explicable. The negative correlation existing between the two methods for calcium determination was investigated further in an attempt to determine the causative effect. The differences of the chemical minus the flame spectrophotometric determinations are plotted in Figure 16. It appeared that the principle reason for the negative correlation might be attributed to the analysis of the femur ash from the pigs receiving the colloidal clay. The chemical determinations for these bones were consistently higher than for the remainder of the femurs. The reverse was true in the case of the spectrophotometric determinations.

The very origin of the colloidal clay would make it very likely to contain other elements. As pointed out by Duckworth and Hill (1953) skeletal tissue possesses an affinity for the retention of elements not considered necessary for metabolic and structural functions of bone tissue, if they are present in the diet. In light of this information and the knowledge that different elements may enhance or suppress the characteristic spectral emmission of an element, it appears highly feasible to think that the colloidal clay contained such an element(s) to exert this effect.

Figure 16. Experiment 593. Deviations between chemical and flame spectrophotometric analysis for calcium content of femur ash
(Deviation = chemical-spectrophotometric)

DEVIATIONS BETWEEN CHEMICAL AND FLAME SPECTROPHOTOMETRIC ANALYSIS FOR CALCIUM IN FEMUR ASH
(DEVIATION = CHEMICAL — SPECTRO - PHOTMETRIC)



Experiments 605 and 605-A

The incidence of skeletal abnormalities was greatly decreased in these two experiments as compared with the coincidental ones reported by Roberts (1953). With very few exceptions, the average amount of feed needed per pound of gain in these experiments was less than that reported in the earlier studies. This would indicate an apparent better utilization of phosphorus and calcium by pigs in experiments 605 and 605-A, as compared with those reported on by Roberts (1953).

Aside from individual variations in animal response, there are only two suggestions offered as possible explanations for the divergence of results. The major dietary difference between the two sets of experiments was the use of brewers' grits when low-phosphorus rations were used in experiments 605 and 605-A instead of pearled corn starch as used by Roberts (1953). It may be possible that brewers' grits provided nutritional factors not afforded to the animals by pearled corn starch. The other factor that might have a bearing on the differences of animal response is the pre-experimental nutritional history of the experimental animals. Quite often overlooked is the effect such factors might have when attempting to define the requirement of a species for a given nutrient.

The flame spectrophotometric determination of calcium, potassium, sodium and magnesium of the femur ash from pigs in experiments 605 and 605-A revealed no significant differences except for a decrease of potassium with age. Similar data were not available from Roberts (1953) for comparison.

All other criteria of response are considered in combination with those of Roberts (1953).

Pooled Average Results of Experiments 605, 605-A, 557-1 and 557-2

Statistical analysis

It was desired to determine if there was a response criterion which would provide an accurate estimate of the adequacy of the dietary level of calcium and phosphorus for the growing pig, without performing a detailed, complicated analysis of body tissue. It is also apparent that standard chemical analysis will not adequately describe alterations which may occur in osseous tissue. Therefore, the average daily gain, breaking strength of femurs and ash content of the femurs were related to the levels of dietary calcium and phosphorus by a multiple regression procedure. All of the pooled data were subjected to an analysis of variance according to the plans in Tables 28 and 29.

Seasonal effect was statistically significant for average daily gain only at the 100 pound weight. However, the fact that there was an increase in breaking strength during the summer, significant at the $P = .01$ level, as well as a highly significant increase in femur ash during the winter, might possibly indicate that sunlight furnished a factor(s) which enhanced calcium and phosphorus utilization other than irradiation of provitamin D in the animals' skin. This is not in accordance with Loeffel (1931) who stated that direct sunlight or cod liver oil was equally effective in increasing ash content or breaking strength of bones from growing swine.

Since the chemical analyses of the femur ash in experiments 605 and 605-A revealed no significant chemical difference it would suggest that the difference in bone ash and breaking strength between season might be attributed to some physical or structural changes occurring in the bone mineral, per se.

A satisfactory explanation cannot be offered for the differences occurring in fat and water content of the femurs.

Multiple regression analysis. The highly significant multiple correlation coefficients (R) indicate a high degree of association between the dependent variables (response criteria) and the independent (dietary calcium and phosphorus levels) variables. The R^2 values indicate the amount of the total variability in the response of the dependent variable which can be attributed to the independent variable. These values ranged from 66.9 to 75.7 for average daily gains, 75.9 to 92.7 for breaking strength of femurs and 75.0 to 88.5 for femur ash content. This would suggest that both breaking strength and ash content of femurs provided a more critical estimate than average daily gain of the adequacy of the dietary calcium and phosphorus levels.

The standard partial regression coefficients (b') are arbitrary units indicating how much of the treatment induced variation is due to each term in the multiple regression equation. The values of t for tests of significance of these coefficients indicate that phosphorus is much the more critical element. This is in accordance with the observations of Roberts (1953) and of Hansard and Plumlee (1954). The latter workers utilized radioisotopes to demonstrate that dietary phosphorus intake apparently influenced calcium metabolism less than dietary calcium influenced phosphorus metabolism in growing rats.

The average corn-soybean oil meal ration fed to swine contains approximately 0.32 and 0.18 per cent of phosphorus and calcium respectively. This might mislead one to believe that phosphorus would not be as critical an element in swine ration as calcium. However, it should be remembered that the results of experiment 593 indicated that phosphorus of plant origin did not adequately supply the needs of swine for this element. The majority of the dietary calcium for swine is supplied from inorganic means, and since, of the two elements, phosphorus exerted the most influence on the response of the evaluating criteria it is very important to furnish an adequate amount of this element from other than plant sources.

Predicted Values for Average Daily Gain, Breaking Strength of Femurs and Ash Content of Femurs

The predicted values for the dependent variables were computed using the multiple regression equation resulting from the analysis of the observed data. These values indicate the expected response of the dependent variables to any given combination of independent variables, within the limits of the experimental plan. They provide an estimate of the average daily gain, breaking strength of femurs and/or ash content of femurs which will be obtained when any of the dietary levels of calcium and phosphorus are fed which were included in the experiment reported herein. They also provide a means of estimating the dietary level of these two elements which are necessary to insure the maximum rate of gain and skeletal response by the growing-finishing pig. Three dimensional response surfaces for these three evaluating criteria for the 100 and 200 pound weight groups are shown in Figures 17 through 22.

As shown in Figures 17 and 18, the calcium-phosphorus ratio exerts considerable effect upon rate of gain at both weight periods when the level of dietary phosphorus is less than 0.4 per cent. The rate of gain decreases as the calcium content increases when the diet contains 0.2 and 0.3 per cent of phosphorus.

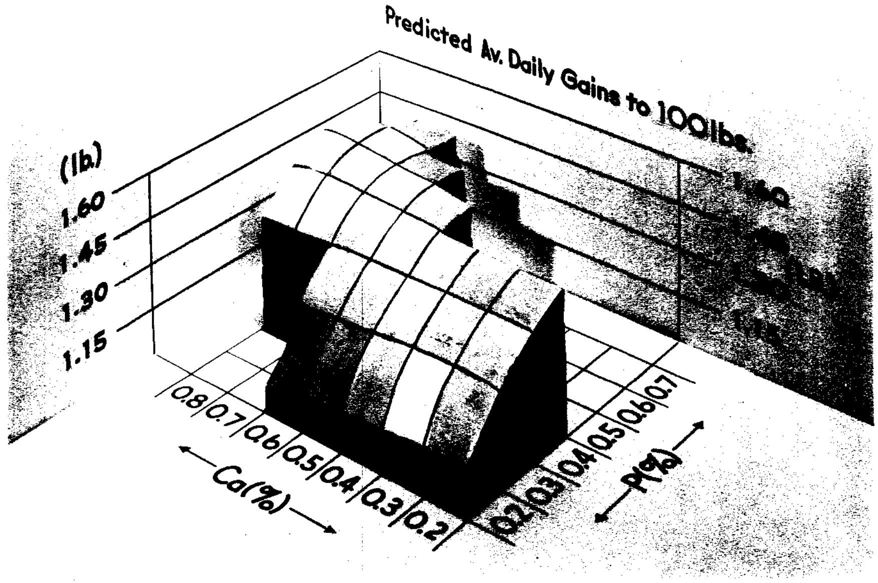
Figure 17 shows the rate of gain of the 100 pound pig to be constant across all levels of calcium when the diet contained 0.4 per cent phosphorus, with calcium exerting some stimulation of gain when 0.5 and 0.6 per cent of phosphorus was provided in the ration.

Increasing the phosphorus content to include 0.6 per cent of this element resulted in increased gains for the 100 pound pig across all levels of calcium tested. The highest rate of gain was obtained when the diet contained 0.8 and 0.6 per cent of calcium and phosphorus, respectively.

Essentially, the same variation in rate of gain occurred in the 200 pound pig when calcium levels were increased in diets containing 0.2 and 0.3 per cent of phosphorus. Rate of gain was somewhat more erratic when the 200 pound pigs received rations containing 0.4 per cent or more of dietary phosphorus. As seen in Figure 18, there were some unexplainable variations in the rate of gain when these higher levels were supplied. However, it can be seen that rate of gain increased across all levels of calcium as the level of dietary phosphorus increased from 0.2

Figure 17. Predicted average daily gain from weaning to 100 pounds of body weight

Figure 18. Predicted average daily gain from weaning to 200 pounds of body weight


Predicted Av. Daily Gains to 100lbs.
(lb.)
1.60
1.45
1.30
1.15
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Ca(%)
0.2
0.3
0.4
0.5
0.6
0.7
P(%)

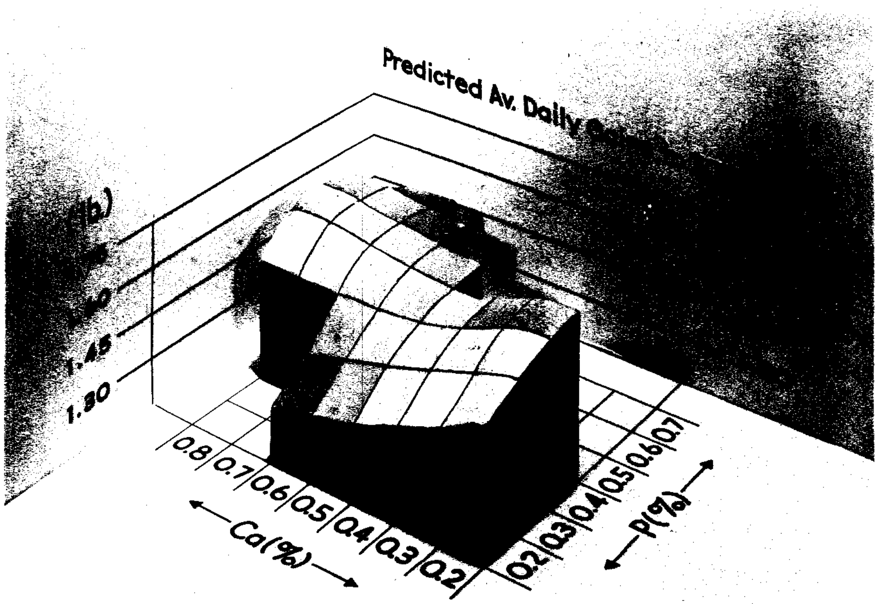
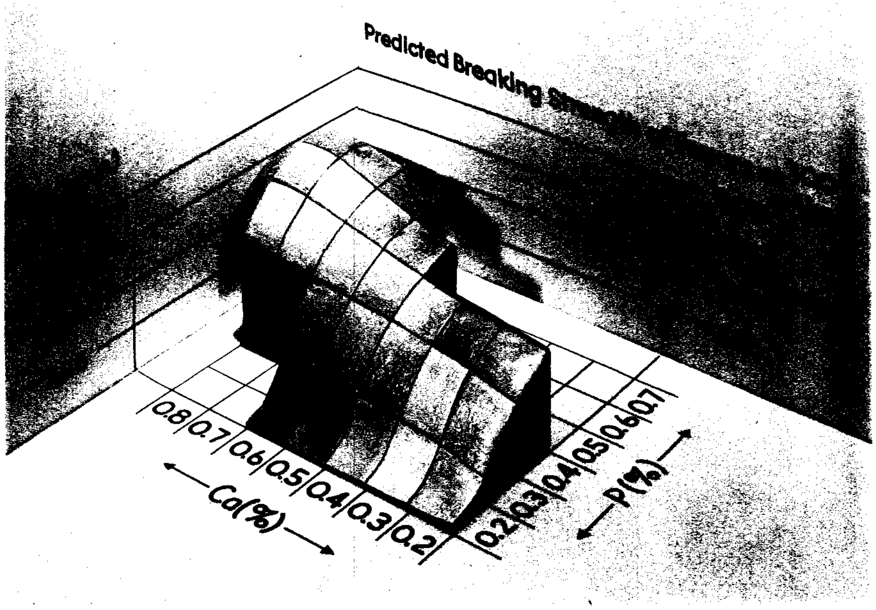
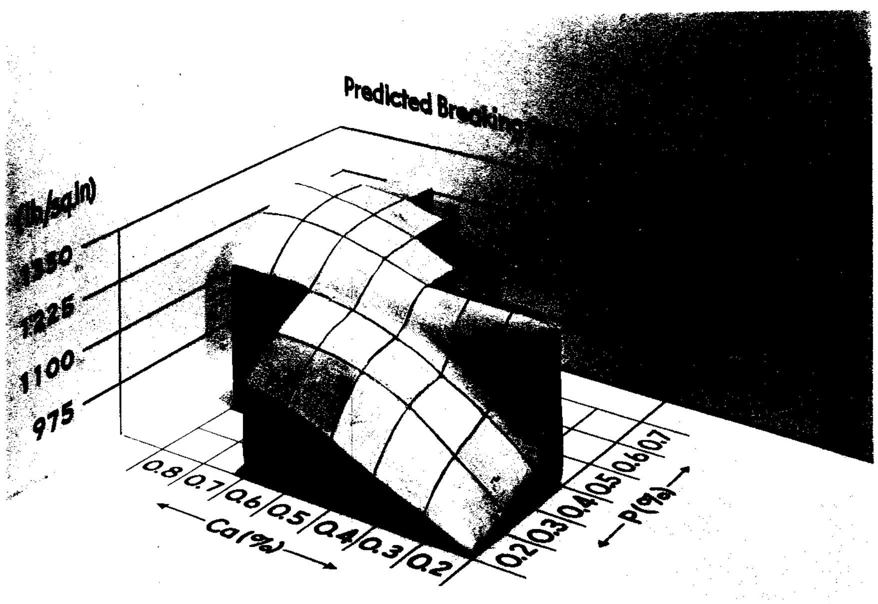

Predicted Av. Daily
1.45
1.30
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Ca(%)
0.2
0.3
0.4
0.5
0.6
0.7
P(%)

Figure 19. Predicted breaking strength of femurs from 100 pound pig

Figure 20. Predicted breaking strength of femurs from 200 pound pig


Predicted Breaking
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Ca(%)
0.2
0.3
0.4
0.5
0.6
0.7
P(%)


Predicted Breaking
(lb/sq.in)
1350
1225
1100
975
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Ca(%)
0.2
0.3
0.4
0.5
0.6
0.7
P(%)

through 0.5 per cent. It would appear that the calcium-phosphorus requirement for optimum gain in this age pig is approximately 0.7 and 0.5 per cent, respectively.

The response surfaces for breaking strength are shown in Figures 19 and 20. Figure 19 shows that breaking strength values for the 100 pound pig were uniformly low across all levels of calcium when 0.2 per cent of phosphorus was supplied. This criterion was increased across all levels of calcium as the level of dietary phosphorus was increased through 0.6 per cent, with the maximum breaking strength occurring when 0.8 per cent calcium and 0.6 per cent phosphorus were supplied in the diet.

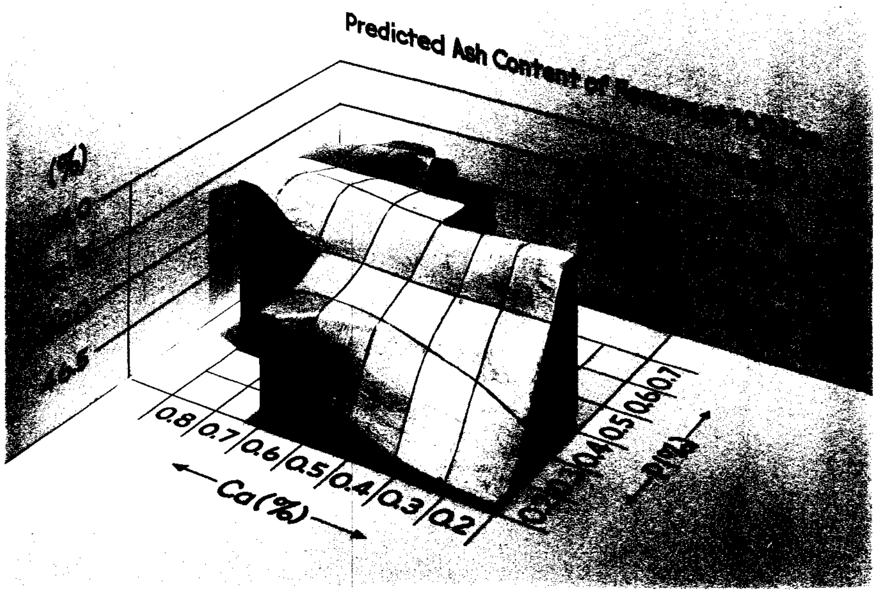
Figure 20 shows that essentially the same effect was found to occur for the 200 pound pig, except that the breaking strength of the femurs increased as either calcium or phosphorus was increased in the diet. The highest breaking strength for the 200 pound pig occurred when the ration contained 0.6 per cent phosphorus and 0.8 per cent calcium.

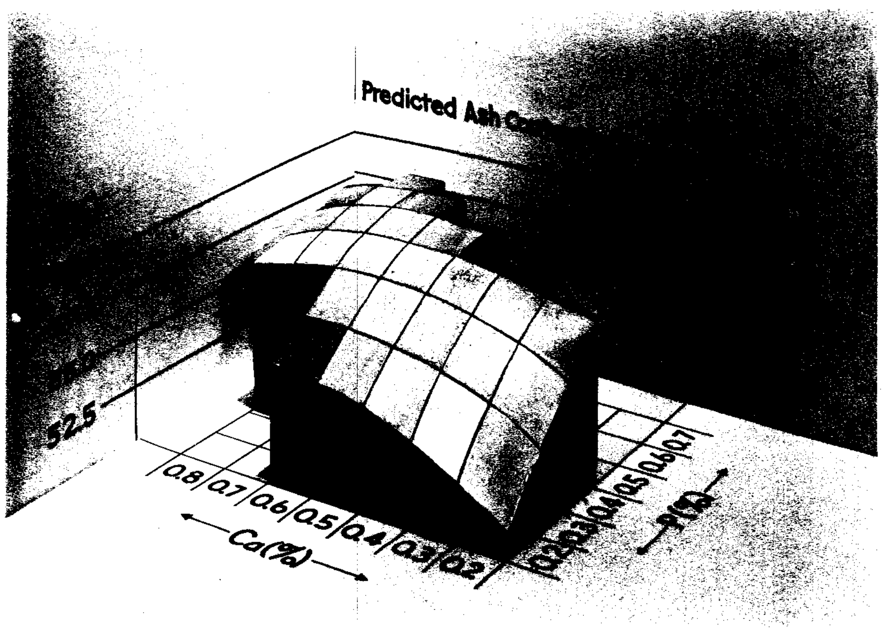
As shown in Figure 21, the response surface is somewhat more irregular for the per cent of femur ash from the 100 pound pig. However, femur ash content increased across levels of dietary calcium from 0.2 through 0.7 per cent as the phosphorus level of the diet increased from 0.2 through 0.6 per cent. When 0.2 per cent of phosphorus was furnished in the diet, the ash content also increased directly with the dietary calcium level. The highest ash content of femurs from the 100 pound pigs occurred when calcium and phosphorus were both supplied at a level of 0.6 per cent of the diet.

The ash content of femurs from 200 pound pigs, as shown in Figure 22,

Figure 21. Predicted ash content of femurs from 100 pound pig

Figure 22. Predicted ash content of femurs from 200 pound pig


Predicted Ash Content
(%)
46.5
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Ca(%)
0.4
0.5
0.6
0.7
P(%)


Predicted Ash
52.5
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Ca(%)
0.4
0.5
0.6
0.7

increased as phosphorus was increased across all levels of calcium. Increasing the calcium level in the diet from 0.2 through 0.6 per cent also gave increases in femur ash content with the maximum value observed when 0.6 per cent of both of the elements were supplied.

The data in Tables 43 through 45 indicated that the predicted values for the 150 pound pig were similar to those for the 100 pound pig.

While adequate performance can be obtained on lower levels, it would appear from these data that in order to insure consistent optimum rate of gain and skeletal performance, the 100 pound pig has a dietary requirement of 0.8 and 0.6 per cent of calcium and phosphorus, respectively. Satisfactory response was obtained from the 200 pound pig when these levels were lowered to 0.7 per cent of calcium and 0.5 per cent of phosphorus. The performance of the pigs was, as adjudged by these measures of response, progressively less consistent as the levels of these two elements were decreased in the diet.

It also appears from the data of experiment 593 that at least thirty per cent of the dietary phosphorus should be obtained from nonplant sources.

These recommended dietary levels of calcium and phosphorus are in excess of those currently recommended by the National Research Council (1953). They are also higher than levels reported in previous investigations in this area, as reviewed by Roberts (1953).

The National Research Council currently recommends that 0.65 and 0.45 per cent of calcium and phosphorus, respectively, be supplied in diets which are fed to 100 pound growing swine. They report that these levels can be lowered to 0.55 and 0.33 per cent of the ration for the 200 pound pig. These recommendations are based upon an evaluation of previous investigations in this field. None of these former studies, when considered individually, employed as comprehensive a range of evaluating criteria as the investigations reported herein.

It would appear that an increased dietary level of these two elements is necessary to assure optimum rate of gain and skeletal development by swine fed well-fortified rations designed to give improved rates of gain and efficiency as compared with those of the previous two or three decades.

SUMMARY AND CONCLUSIONS

Experiment 593

Two replicates of 18 pens of 4 pigs each (total 144 pigs) were fed in concrete dry lot to determine (1) the relative value of colloidal clay with soft phosphate, dicalcium phosphate and steamed bonemeal as phosphorus supplements for growing-finishing swine; (2) the effect of including these three supplements at two different levels in the rations; (3) the effect of chlortetracycline upon the utilization of organic and inorganic phosphorus by the pig; (4) the ability of the pig to utilize phosphorus of plant origin (phytin phosphorus) and (5) to determine the comparative nutritional value of organic and inorganic phosphorus for the growing and finishing pig.

Evaluating criteria were rate of gain, feed efficiency and blood serum phosphorus when the pig reached a body weight of 100 pounds. These criteria, plus breaking strength, weight and ash content of bone, as well as phosphorus, calcium, fluorine, potassium, sodium and magnesium content of the femur ash, were used when the pigs reached the terminating weight of 200 pounds.

A comparison of feeding colloidal clay with either steamed bonemeal or dicalcium phosphate resulted in a significant decrease in rate of gain, feed efficiency and breaking strength of femurs, accompanied by a significant increase in femur ash content and an increase in fluorine content of the femur ash, from pigs receiving the colloidal clay. There was no significant difference in the phosphorus content of bone ash or blood serum due to the type of phosphorus supplement.

Growing-finishing swine did not utilize plant phosphorus as efficiently as inorganic phosphorus, as evidenced by a significantly poorer feed efficiency when the phosphorus level from the three supplements was decreased from 0.30 to 0.18 per cent of the ration. There was also a significant linear increase in average daily gains and feed efficiency when phosphorus from plant sources decreased from 0.50 to 0.35 to 0.20 per cent of the total rations. Inorganic phosphorus was added to maintain 0.5 per cent phosphorus in the ration.

There were inconclusive indications that chlortetracycline may effect phosphorus metabolism in the bone of the growing-finishing pig.

Calcium and Phosphorus Requirements

The calcium and phosphorus requirements of growing-finishing swine were further investigated employing a partial seven by seven factorial design, with dietary levels of calcium and phosphorus ranging from 0.2 through 0.8 and 0.2 through 0.7 per cent, respectively.

Flame spectrophotometric analysis revealed no significant difference in calcium, potassium, sodium or magnesium content of femur ash. There were no significant changes of the phosphorus content of the femur ash. As the dietary phosphorus levels increased there was a significant increase in femur weight and a significant decrease in femur fat content.

A multiple regression analysis involving averages from four pigs per treatment within weight groups revealed 66.9 - 75.7, 75.9 - 92.7 and 75.0 - 88.5 per cent of the variability in average daily gain, breaking strength of femurs and femur ash content was attributable to the variation of calcium and phosphorus in the ration. Of the two elements, phosphorus had much the greater influence on the response criteria.

The dietary calcium and phosphorus needed to insure optimum rate of gain and skeletal response appears to be 0.8 and 0.6, respectively, for the 100 pound pig, and 0.7 and 0.5 per cent for the 200 pound growing-finishing pig. Response to these dietary levels can be effected by the origin of the phosphorus in the diet. This is indicated by the results of the investigation concerned with availability of phosphorus from different sources. It appears that at least 30 per cent of these recommended levels should be derived from a non-plant source.

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APPENDIX

Table 28. Experiment 593. Summary of mean squares from the analysis of variance of growth and feed data[a]

Source of variation	Degrees of freedom	First 8 week period			25 to 200 lb.		
		Daily gain	Daily feed	Feed/gain	Daily gain	Daily feed	Feed/gain
Replication	1	—	—	—	—	—	—
All treatments	17	0.021[b]	0.142	613	0.020[b]	0.240	1339[b]
Plant P. vs. suppl. P.	1	0.056[b]	0.170	292	0.007	0.629	4917[b]
Among plant P.	5	0.032[b]	1.331	672	0.017[b]	0.115	1282[b]
Levels inorg. P.	2	0.068[b]	0.468[b]	796	0.034[b]	0.163	3139[b]
Linear component	1	0.120[b]	0.332	666	0.065[b]	0.122	6050[b]
Quadratic component	1	0.015	0.605[b]	925	0.003	0.204	228
Antibiotic	1	0.008	0.267	456	0.009	0.178	40
Levels P. x Ab.	2	0.008	0.064	656	0.003	0.035	46
Treatment among P. suppl.	11	0.013	0.084	616	0.021[b]	0.262[b]	1039[b]
Among P. suppl.	2	0.055[b]	0.117	458	0.091[b]	0.280[b]	802[b]
B.M. vs. Dical. + C.C.	1	0.038[b]	0.018	683	0.065[b]	0.101	901[b]
Dical. vs. C.C.	1	0.072[b]	0.216	233	0.118[b]	0.459	702
Levels inorg. P.	1	0.000	0.498[b]	2667	0.000	1.955	7957[b]
Antibiotic	1	0.007	0.040	1	0.026[b]	0.027	495
Suppl. x levels P.	2	0.010	0.035	464	0.012	0.076	8
Suppl. x Ab.	2	0.001	0.016	130	0.000	0.081	484
Levels P. x Ab.	1	0.001	0.011	155	0.000	0.025	26
Suppl. x level P. x Ab.	2	0.002	0.016	926	0.004	0.001	185
Expt. error (a)	17	0.007	0.101	486	0.005	0.054	172
All causes	35	—	—	—	—	—	—

[a]Analyses of variance performed using the pen of 4 pigs as the experimental unit
[b]Treatment effects significant at P = .05 or less

Table 29. Experiment 593. Summary of mean squares from the analysis of variance of femur ash data[a]

Source of variation	Degrees of freedom	Analysis of femur ash: P	Ca: Chem.	Ca: Spectro.	Mg	Na	K
Replication	1	—	—	—	—	—	—
All treatments	17	.182	32.37	24.16	7.89	3.73	0.79
Plant P. vs. suppl. P.	1	.312	0.01	30.16	3.69	8.17	0.01
Among plant P.	5	.169	11.47	8.85	9.83	0.97	0.49
Levels inorg. P.	2	.095	7.30	17.85	15.03	1.17	0.61
Linear component	1	.122	5.04	8.82	2.53	1.09	0.81
Quadratic component	1	.068	9.56	26.88	27.52	1.24	0.40
Antibiotic	1	.510	22.41	1.84	8.50	0.44	1.22
Levels P. x Ab.	2	.072	10.18	3.62	5.29	1.04	0.02
Treatment among P. suppl.	11	.177	44.81	30.57	7.40	4.59	0.99
Among P. suppl.	2	.169	185.63	132.15	0.35	12.88	2.52
B.M. vs. Dical. + C.C.	1	.038	155.17[b]	174.29[b]	0.28	11.89[b]	0.08
Dical. vs. C.C.	1	.300	216.09[b]	90.01[b]	0.42	13.88[b]	4.88[b]
Levels inorg. P.	1	.130	8.94	18.73	5.90	4.64	0.83
Antibiotic	1	.827	3.19	0.38	18.55	1.90	0.72
Suppl. x levels P.	2	.120	11.56	13.98	2.49	0.40	0.15
Suppl. x Ab.	2	.102	7.11	5.00	11.51	1.62	1.96
Levels P. x Ab.	1	.092	38.14	0.12	0.22	1.05	0.00
Suppl. x level P. x Ab.	2	.058	17.02	7.41	14.00	6.54	0.06
Expt. error (a)	17	.296	15.54	6.17	6.33	2.31	0.67
Sex	1	.845	29.61	54.02[b]	574.40[b]	22.96	—
Sex x all treatments	17	.052	8.99	3.59	5.07	0.76	—
Expt. error (b)	17	.270	10.92	11.92	7.96	21.75	—
All causes	70[c]	—	—		—	—	—

[a]Analysis of variance performed with the experimental unit consisting of 2 pigs of opposite sex, from the same pen

[b]Treatment effect significant at P = .05 level

[c]One degree of freedom used for estimated value

Table 30. Experiment 593. Summary of mean squares from the analysis of variance of bone data[a]

Source of variation	Degrees of freedom	Femur wt.	Breaking strength	% water	% fat	% ash
Replication	1	—	—	—	—	—
All treatments	17	781.68	25366	14.56	24.84	2.184
Plant P. vs. suppl. P.	1	2422.66	11467	19.79	45.12	0.004
Among plant P.	5	642.36	13578	9.83	35.09	1.611
Levels inorg. P.	2	1434.93	13743	11.17	67.78	2.725
Linear component	1	1779.06	13340	9.79	131.22[b]	4.516
Quadratic component	1	1090.80	14145	12.54	4.34	0.935
Antibiotic	1	0.29	26334	0.10	1.96	0.602
Levels P. x Ab.	2	170.84	7034	13.34	18.98	1.000
Treatment among P. suppl.	11	695.83	31988	16.23	18.33	2.643
Among P. suppl.	2	58.32	110600[c]	40.89	27.08	5.296[c]
B.M. vs. Dical. + C.C.	1	87.88	134775[c]	21.13	2.50	0.128
Dical. vs. C.C.	1	28.76	86424	60.65[c]	51.66	10.465[c]
Levels inorg. P.	1	2536.90	315	3.88	62.08	2.125
Antibiotic	1	2967.04	25254	13.13	1.00	0.130
Suppl. x levels P.	2	153.86	12328	8.64	7.12	3.996
Suppl. x Ab.	2	35.97	9092	26.48	28.18	0.008
Levels P. x Ab.	1	1230.52	1271	4.73	0.11	0.152
Suppl. P. x level P. x Ab.	2	211.70	30498	2.40	6.85	4.032
Expt. error (a)	17	689.82	19522	9.05	17.88	1.113
Sex	1	3.80	58140	454.05[d]	10.73	7.157
Sex x all treatments	17	459.40	7635	5.90	13.05	2.302
Expt. error (b)	17	402.74	18519	17.30	18.37	3.294
All causes	70[e]	—	—	—	—	—

[a]Analysis of variance performed with the experimental unit, comprised of 2 pigs of opposite sex from the same pen

[b]Linear effect of level of inorganic P. significant at P = .05 or less

[c]Treatment effect significant at P = .05 or less

[d]Sex effect significant at P = .05 or less

[e]One degree of freedom used for estimated value

Table 31. Summary of mean squares from the analysis of variance of average daily gain, breaking strength of femurs and ash content of femurs[a]

Source of variation	Degrees of freedom	Average daily gain			Breaking strength of femurs			Ash content of femurs		
		100	150	200	100	150	200	100	150	200
Seasons	1	.175[b]	.006	.053	7,006	153,586[c]	214,276[c]	211.4[c]	39.6[c]	141.6[c]
Reps. within season	2	.753[c]	.001	.549[c]	11,021	10,826	81,649	69.1[c]	30.1[b]	8.8
Rations	24	.081[c]	.066	.074[b]	104,289[c]	101,241[c]	110,238[c]	34.6[c]	36.0[c]	15.2[c]
Remainder	72	.032	.041	.036	18,237	23,556	33,373	10.5	4.3	5.2
Rat. x seas.	24	.029	.056	.032	23,180	14,319	31,268	9.8	4.1	4.8
Rat. x seas./rep.	48	.033	.034	.037	15,765	28,174	34,426	10.8	4.3	5.3
Total	99	—	—	—	—	—	—	—	—	—

[a]From analysis of variance for pooled data of experiments 557, 557-1, 605 and 605-A
[b]Significant at P = .05 level
[c]Significant at P = .01 level

Table 32. Summary of mean squares from the analysis of variance of water and fat content of femurs, of phosphorus content of femur ash and femur weight[a]

Source of variation	Degrees of freedom	Water content of femurs	Fat content of femurs[b]	P content of femur ash	Femur weight
Replication	3	62.29[c]	454.85[d]	5.09	1205.34
Weights	2	5373.49[d]	902.94[d]	1.90	186227.83[d]
Rep. x wt. (error a)	6	12.98	26.29	2.20	418.39
Rations	24	47.44[d]	101.03[d]	0.25	945.70[d]
Rat. x rep. (error b)	72	7.86	19.08	0.23	241.49
Rat. x wt.	48	7.06	7.68	0.16	200.00
Rat. x wt. x rep.(error c)	140	8.16	8.61	0.24	221.41
Total	295	--	--	--	--

[a]From analysis of variance of pooled data of experiments 557-1, 557-2, 605 and 605-A

[b]Water-free basis

[c]Significant at P = .05 level

[d]Significant at P = .01 level

Table 33. Experiments 605 and 605-A. Summary of mean squares from the analysis of variance of sodium, magnesium, calcium and potassium content of femur ash

Source of variation	Degrees of freedom	Flame spectrophotometric analysis[a]			
		Sodium	Magnesium	Calcium	Potassium
Replication	1	115.91	213.13	1.33	0.91
Weight	2	25.91	11.66	53.15	44.99[b]
Rep. x wt. (error a)	2	143.90	78.36	153.48	3.50
Rations	24	2.73	0.76	2.30	1.01
Rat. x rep. (error b)	24	3.29	1.19	6.24	1.40
Rat. x wt.	48	2.64	0.86	2.21	0.51
Rat. x wt. x rep.(error c)	45	1.76	1.28	3.27	0.89
Total	146	--	--	--	--

[a]Femur ash
[b]Significant at P = .05 level

Table 34. Summary of average daily gain[a] (lbs.)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	1.39	1.14	1.14	1.13	1.18		
	150	1.46	1.32	1.27	1.44	1.34		
	200	1.42	1.38	1.44	1.23	1.27		
0.3	100	1.36	1.36	1.35	1.18	1.41		
	150	1.60	1.54	1.44	1.51	1.54		
	200	1.76	1.68	1.66	1.50	1.56		
0.4	100	1.41	1.38	1.43	1.48	1.54	1.57	1.38
	150	1.36	1.48	1.57	1.63	1.64	1.57	1.62
	200	1.67	1.65	1.56	1.64	1.60	1.64	1.67
0.5	100				1.48	1.46	1.47	1.52
	150				1.70	1.72	1.70	1.67
	200				1.50	1.52	1.65	1.67
0.6	100					1.59	1.58	1.50
	150					1.49	1.57	1.64
	200					1.56	1.58	1.68
0.7	100						1.50	
	150						1.70	
	200						1.72	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 35. Summary of femur weights at time of soft tissue removal[a] (grams)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%) 0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	122.3	120.0	123.2	122.2	117.0		
	150	168.0	170.4	159.5	164.5	177.2		
	200	188.8	204.2	201.2	208.2	204.7		
0.3	100	119.4	122.2	126.1	125.2	132.5		
	150	157.1	177.4	181.5	171.2	161.5		
	200	199.5	222.1	204.5	211.0	222.0		
0.4	100	128.6	127.0	133.9	123.0	128.4	125.2	129.1
	150	167.2	168.6	196.8	163.4	181.3	178.6	183.5
	200	196.0	212.2	231.4	223.6	215.4	204.5	215.8
0.5	100				130.4	135.4	141.0	141.5
	150				187.4	191.9	180.1	186.7
	200				205.6	231.5	236.2	229.9
0.6	100					139.6	139.6	139.6
	150					181.6	182.3	183.8
	200					235.2	221.0	220.2
0.7	100						124.4	
	150						188.0	
	200						225.2	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 36. Summary of breaking strength of femurs[a] (lbs. per sq. in.)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%) 0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	400	236	286	320	319		
	150	434	730	584	787	821		
	200	926	856	966	1193	1088		
0.3	100	502	415	413	476	504		
	150	755	849	801	863	819		
	200	900	1042	924	1150	1179		
0.4	100	474	539	552	596	612	654	641
	150	746	882	936	784	893	894	1059
	200	986	1005	1253	1271	1208	1079	1219
0.5	100				642	728	688	801
	150				1045	1013	1062	1073
	200				1137	1295	1386	1348
0.6	100					772	756	718
	150					988	979	1094
	200					1332	1292	1449
0.7	100						646	
	150						1022	
	200						1219	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 37. Summary of water content of ground femurs[a] (per cent)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%) 0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	51.2	51.2	51.4	50.3	49.8		
	150	44.4	39.4	41.2	40.2	39.4		
	200	34.1	35.3	37.0	31.2	31.0		
0.3	100	51.6	49.3	49.7	46.8	47.3		
	150	41.4	39.2	40.2	39.6	38.9		
	200	36.0	35.6	33.1	32.6	31.6		
0.4	100	49.6	46.7	46.9	46.6	46.1	44.4	43.8
	150	42.0	39.2	38.2	38.8	39.3	37.2	38.7
	200	34.2	33.7	30.8	32.2	31.7	32.8	34.2
0.5	100				46.0	45.0	46.9	43.2
	150				39.0	38.1	37.4	35.3
	200				31.0	31.6	32.1	31.8
0.6	100					43.8	45.3	44.5
	150					35.8	35.5	37.4
	200					29.9	29.9	32.2
0.7	100						44.5	
	150						35.8	
	200						31.6	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 38. Summary of fat content of water-free femurs[a] (per cent)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%) 0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	25.9	27.8	28.8	28.7	30.0		
	150	33.2	33.0	33.5	30.9	32.4		
	200	33.2	32.1	29.8	33.1	34.6		
0.3	100	23.3	24.4	25.2	27.4	27.0		
	150	30.2	29.4	30.3	29.8	29.4		
	200	35.2	32.2	33.1	32.3	29.9		
0.4	100	26.1	27.0	23.7	22.4	22.6	22.8	23.7
	150	30.8	31.4	28.9	27.4	26.5	25.1	23.6
	200	32.4	32.1	28.3	27.9	26.8	27.8	28.6
0.5	100				22.4	21.1	19.9	20.0
	150				24.0	25.0	24.2	23.5
	200				29.5	27.4	27.2	24.3
0.6	100					21.1	20.1	21.2
	150					26.0	25.5	22.8
	200					28.3	27.7	25.7
0.7	100						20.2	
	150						25.8	
	200						27.8	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 39. Summary of ash content of water-free, fat-free femurs[a] (per cent)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	46.1	46.2	43.0	45.9	49.6		
	150	45.6	50.7	49.8	52.4	52.8		
	200	53.2	53.2	54.4	56.6	56.7		
0.3	100	47.7	45.6	46.0	46.8	47.7		
	150	51.9	53.1	51.1	51.6	52.7		
	200	54.4	55.0	55.6	55.4	57.0		
0.4	100	49.4	49.2	50.5	50.4	51.2	49.4	52.2
	150	51.8	54.0	53.8	54.6	54.7	56.5	57.2
	200	55.7	57.2	58.8	58.3	58.4	57.4	57.5
0.5	100				51.3	52.7	51.9	53.3
	150				55.4	56.5	56.5	58.8
	200				58.6	60.0	58.7	57.0
0.6	100					53.3	52.8	52.1
	150					56.8	57.8	56.6
	200					59.3	59.8	57.9
0.7	100						52.2	
	150						56.1	
	200						58.7	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 40. Summary of phosphorus content of femur ash[a] (per cent)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	17.4	17.8	17.8	17.5	18.4		
	150	18.1	18.1	18.0	18.0	18.2		
	200	18.1	17.9	17.9	18.0	17.8		
0.3	100	17.6	17.7	17.8	17.6	17.9		
	150	18.6	18.2	18.4	17.9	17.9		
	200	18.0	18.2	17.9	18.0	17.7		
0.4	100	17.9	18.2	18.1	18.0	17.8	17.7	17.8
	150	18.4	18.6	18.4	17.9	17.6	18.1	18.1
	200	18.1	18.3	17.8	18.0	18.0	18.1	18.1
0.5	100				18.2	17.8	17.6	18.0
	150				17.8	18.0	18.0	18.1
	200				18.0	18.0	17.9	18.1
0.6	100					17.9	18.1	18.2
	150					18.1	18.5	18.3
	200					17.9	18.0	18.2
0.7	100						18.0	
	150						18.5	
	200						17.8	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 41. Summary of feed required per pound of gain[a] (lbs.)

P in ration (%)	Ca in ration (%) 0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	2.90	3.14	2.98	2.97	3.04		
0.3	2.78	2.86	2.98	3.05	3.08		
0.4	2.86	3.01	2.90	3.06	2.97	2.98	3.05
0.5				3.06	2.98	3.02	3.04
0.6					3.04	3.04	3.06
0.7						3.08	

[a]Average of experiments 557-1, 557-2, 605 and 605-A

Table 42. Summary of multiple correlation coefficients[a] (R)

Weight at kill	Average daily gain	Breaking strength of femurs	Ash content of fat-free, water-free femurs
100	0.870[b]	0.963[b]	0.866[b]
150	0.818[b]	0.903[b]	0.941[b]
200	0.827[b]	0.871[b]	0.940[b]

[a]From multiple regression analysis of pooled data of experiments 557-1, 557-2, 605 and 605-A

[b]Significant at P = .01 level

Table 43. Summary of partial regression coefficients[a]
(b)

Weight at kill (lbs.)	Y intercept	Ca	P	Ca^2	P^2	CaP
			Average daily gain			
100	+0.923	-0.471	+2.355	-0.015	-2.735	+1.252
150	+1.091	-0.076	+1.922	-0.790	-3.558	+2.709
200	+1.386	-1.671	+2.598	+1.053	-3.246	+1.243
			Breaking strength of femurs			
100	-95.784	-277.742	+2658.791	+32.232	-3044.443	+1207.448
150	+72.094	+749.258	+2157.508	+92.073	-1047.486	-1259.393
200	+491.461	+999.589	+1162.370	-862.819	-1521.781	+958.737
			Ash content of femurs			
100	+37.936	+4.723	+33.768	+32.434	+36.843	-91.244
150	+39.115	+11.058	+41.298	+6.463	-20.145	-25.307
200	+43.346	+26.896	+26.533	-14.684	-3.533	-25.680

[a]From multiple regression analysis of pooled data of experiments 557-1, 557-2, 605 and 605-A.

Table 44. Summary of standard partial regression coefficients[a] (b')

Wt. at kill (lbs.)	C	P	Ca^2	P^2	CaP
			Average daily gain		
100	-0.638	+2.383	-0.021	-2.330	+1.224
150	-0.114	+2.153	-1.198	-3.355	+2.931
200	-2.375	+2.758	+1.512	-2.900	+1.275
			Breaking strength of femurs		
100	-0.332	+2.373	+0.039	-2.287	+1.041
150	+0.909	+1.954	+0.113	-0.799	-1.102
200	+1.162	+1.009	-1.014	-1.112	+0.804
			Ash content of femurs		
100	+0.310	+1.655	+2.152	+1.520	-4.321
150	+0.711	+1.984	+0.420	-0.815	-1.175
200	+2.662	+1.962	-1.469	-0.220	-1.834

[a]From multiple regression analysis of pooled data of experiments 557-1, 557-2, 605 and 605-A

Table 45. t for standard partial regression coefficients[a]

Wt. at kill (lbs.)	C	P	Ca^2	P^2	CaP
		Average daily gain			
100	0.97	3.73[b]	0.02	2.44[c]	0.91
150	0.15	2.90[b]	1.17	3.02[c]	1.88
200	3.17[b]	3.79[b]	1.51	2.67[c]	0.83
		Breaking strength of femurs			
100	0.93	6.83[b]	0.08	4.41[b]	1.43
150	1.59	3.52[b]	0.15	0.96	0.94
200	1.77	1.59	1.16	1.17	0.60
		Ash content of femurs			
100	0.47	2.56[c]	2.42[c]	1.57	3.18[b]
150	1.58	4.54[b]	0.70	1.25	1.28
200	5.86[b]	4.44[b]	2.42[c]	0.33	1.98

[a]From multiple regression analysis of pooled data of experiments 557-1, 557-2, 605 and 605-A

[b]Significant at P = .01 level

[c]Significant at P = .05 level

Table 46. Predicted breaking strength of femurs from swine fed different levels of calcium and phosphorus
(lbs. per sq. in.)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	308	306	305	304	304		
	150	565	619	676	733	793		
	200	867	943	1002	1043	1067		
0.3	100	446	456	467	478	490		
	150	703	745	788	834	881		
	200	926	1012	1080	1131	1165		
0.4	100	523	545	568	591	616	640	666
	150	820	849	880	913	948	984	1023
	200	955	1050	1128	1189	1232	1258	1267
0.5	100				644	680	716	754
	150				972	994	1018	1044
	200				1216	1269	1305	1323
0.6	100					683	732	782
	150					1019	1030	1043
	200					1276	1321	1349
0.7	100						687	
	150						1022	
	200						1306	

Table 47. Predicted average daily gain for swine fed different levels of calcium and phosphorus
(lbs.)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	1.24	1.22	1.19	1.17	1.15		
	150	1.39	1.40	1.39	1.37	1.33		
	200	1.53	1.44	1.38	1.33	1.30		
0.3	100	1.36	1.35	1.34	1.33	1.32		
	150	1.46	1.50	1.52	1.52	1.50		
	200	1.66	1.58	1.52	1.49	1.47		
0.4	100	1.43	1.43	1.44	1.44	1.44	1.44	1.44
	150	1.46	1.52	1.57	1.60	1.61	1.61	1.59
	200	1.71	1.65	1.60	1.58	1.58	1.60	1.64
0.5	100				1.49	1.50	1.52	1.53
	150				1.60	1.65	1.67	1.68
	200				1.61	1.62	1.66	1.71
0.6	100					1.51	1.54	1.57
	150					1.61	1.66	1.70
	200					1.60	1.64	1.74
0.7	100						1.51	
	150						1.58	
	200						1.57	

Table 48. Predicted ash content of femurs from swine fed different levels of calcium and phosphorus
(per cent)

P in ration (%)	Wt. at kill (lbs.)	Ca in ration (%)						
		0.2	0.3	0.4	0.5	0.6	0.7	0.8
0.2	100	44.8	45.0	45.9	47.5	49.7		
	150	48.0	48.9	50.0	51.2	52.5		
	200	52.3	53.7	54.9	55.7	56.3		
0.3	100	48.1	47.5	47.6	48.2	49.5		
	150	50.6	51.3	52.1	53.0	54.1		
	200	54.2	55.4	56.3	56.9	57.2		
0.4	100	52.3	50.7	49.8	49.6	49.9	51.0	52.7
	150	52.9	53.3	53.8	54.5	55.3	56.2	57.3
	200	56.1	57.1	57.7	58.0	58.1	57.8	57.3
0.5	100				51.7	51.2	51.3	52.1
	150				55.6	56.1	56.8	57.6
	200				59.1	58.9	58.4	57.6
0.6	100					53.1	52.3	52.2
	150					56.5	56.9	57.5
	200					59.6	58.8	57.8
0.7	100						51.7	
	150						56.7	
	200						59.2	